US008829849B2

(12) **United States Patent**
Kim et al.

(10) **Patent No.: US 8,829,849 B2**
(45) **Date of Patent: Sep. 9, 2014**

(54) **ROOF TYPE CHARGING APPARATUS USING RESONANT POWER TRANSMISSION**

(75) Inventors: **Dong Zo Kim**, Yongin-si (KR); **Sang Wook Kwon**, Seongnam-si (KR); **Yun Kwon Park**, Dongducheon-si (KR); **Eun Seok Park**, Suwon-si (KR); **Young Tack Hong**, Seongnam-si (KR); **Young Ho Ryu**, Yongin-si (KR); **Nam Yun Kim**, Seoul (KR); **Jin Sung Choi**, Gimpo-si (KR)

(73) Assignee: **Samsung Electronics Co., Ltd.**, Suwon-si (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 136 days.

(21) Appl. No.: **13/210,233**

(22) Filed: **Aug. 15, 2011**

(65) **Prior Publication Data**

US 2012/0056579 A1 Mar. 8, 2012

(30) **Foreign Application Priority Data**

Sep. 8, 2010 (KR) 10-2010-0087939

(51) **Int. Cl.**
H02J 7/00 (2006.01)

(52) **U.S. Cl.**
USPC **320/108**; 320/114; 320/115

(58) **Field of Classification Search**
USPC 320/108, 114, 115; 340/854.6, 854.8, 340/855.8; 455/269, 270, 573
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,821,731	A *	10/1998	Kuki et al.	....	320/108
7,504,802	B2 *	3/2009	Bersenev	....	320/108
7,622,891	B2 *	11/2009	Cheng et al.	....	320/108
7,916,467	B2 *	3/2011	Hotelling et al.	....	361/679.41
2003/0173473	A1 *	9/2003	Mackay et al.	....	248/125.7
2008/0014897	A1 *	1/2008	Cook et al.	....	455/343.1
2009/0218985	A1 *	9/2009	Hallett	....	320/108
2009/0251101	A1 *	10/2009	Phillips et al.	....	320/108
2010/0314038	A1 *	12/2010	Tanuma	....	156/249
2010/0315038	A1 *	12/2010	Terao et al.	....	320/108
2011/0018499	A1 *	1/2011	Fujiwara	....	320/108
2011/0127953	A1 *	6/2011	Walley et al.	....	320/108
2012/0153893	A1 *	6/2012	Schatz et al.	....	320/108

FOREIGN PATENT DOCUMENTS

JP	2006-314181	11/2006
JP	2008-172872	7/2008
JP	2008-312294	12/2008
KR	10-2005-0096068	10/2005
KR	20-0411082	3/2006
KR	10-2007-0028896	3/2007

* cited by examiner

Primary Examiner — Richard V Muralidar
Assistant Examiner — Michael Dibenedetto
(74) *Attorney, Agent, or Firm* — NSIP Law

(57) **ABSTRACT**

Provided is a roof-type charging apparatus that charges multi-target device, while transmitting a resonance power. A roof-type charging apparatus using resonance power transmission includes a source resonance unit configured to transmit resonance power including a source resonator having a generally planar loop configuration and defining a space therein; a receiving unit configured to receive the resonance power transmitted from the source resonator; and a connecting unit configured to separate the source resonator and the receiving unit by a predetermined distance.

22 Claims, 18 Drawing Sheets

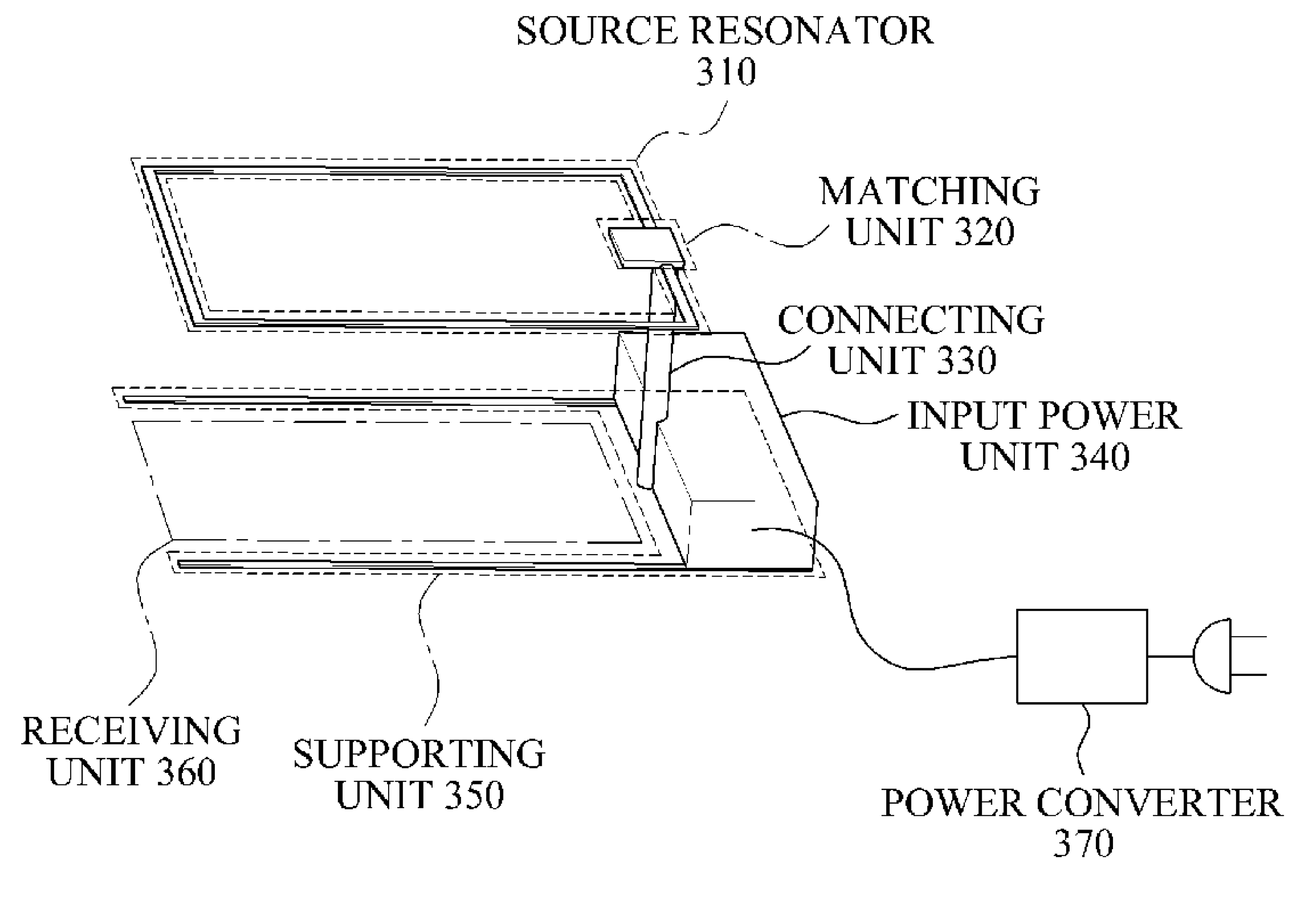
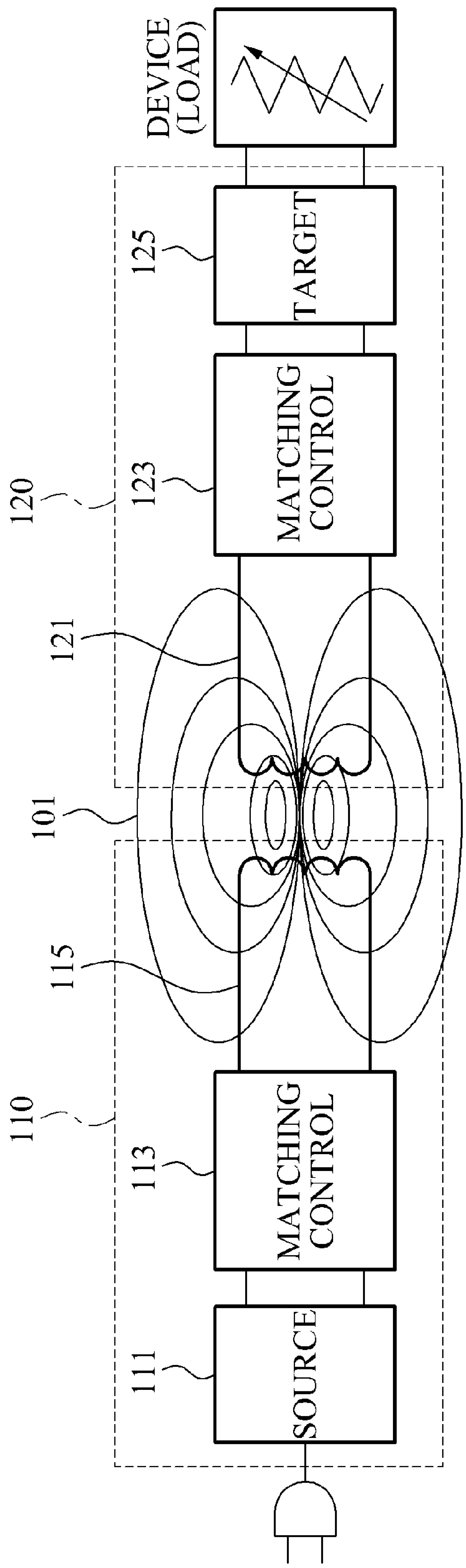


FIG. 1



DEVICE (LOAD)
TARGET
125
MATCHING CONTROL
123
120
121
101
115
110
MATCHING CONTROL
113
SOURCE
111

FIG. 2A

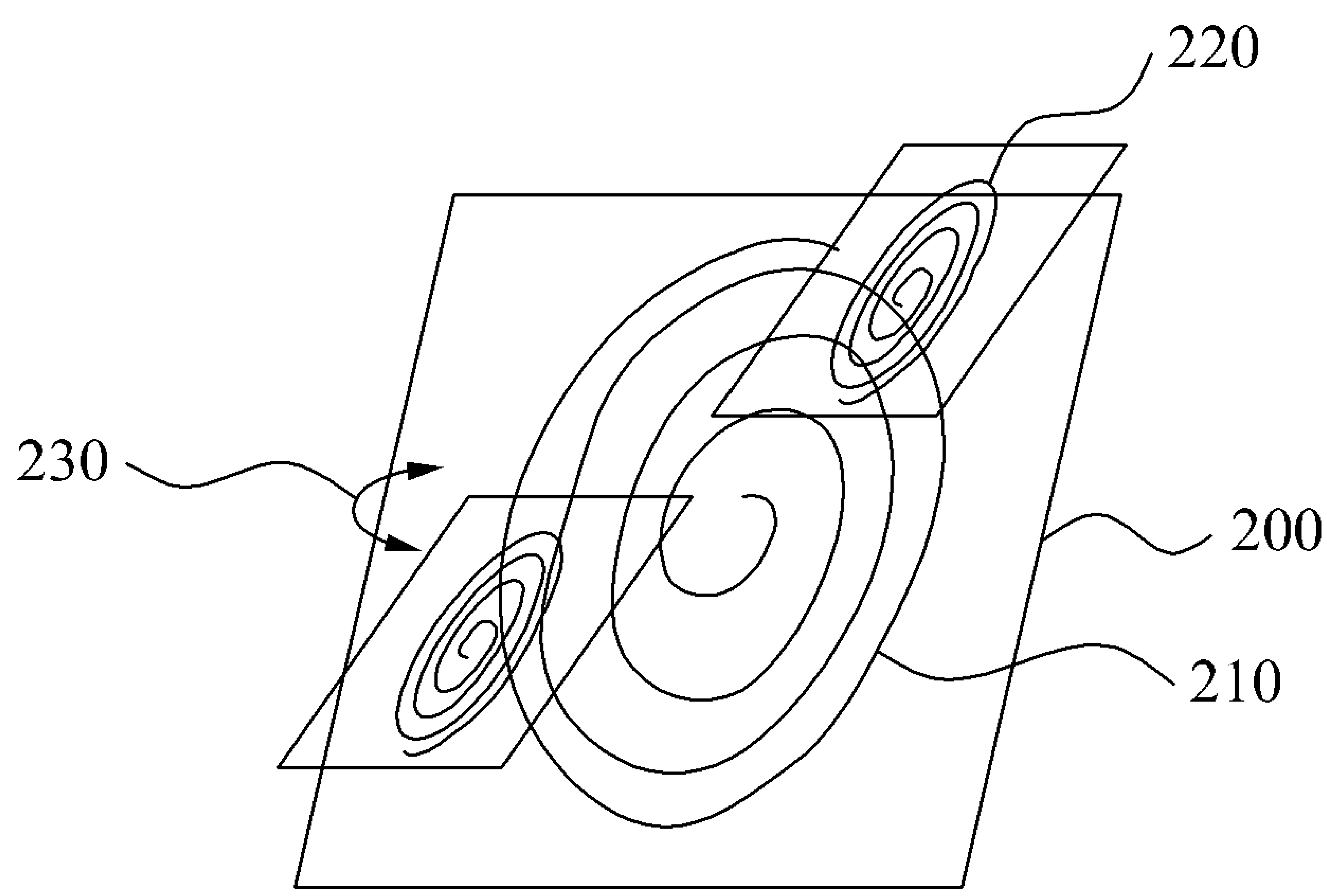


FIG. 2B

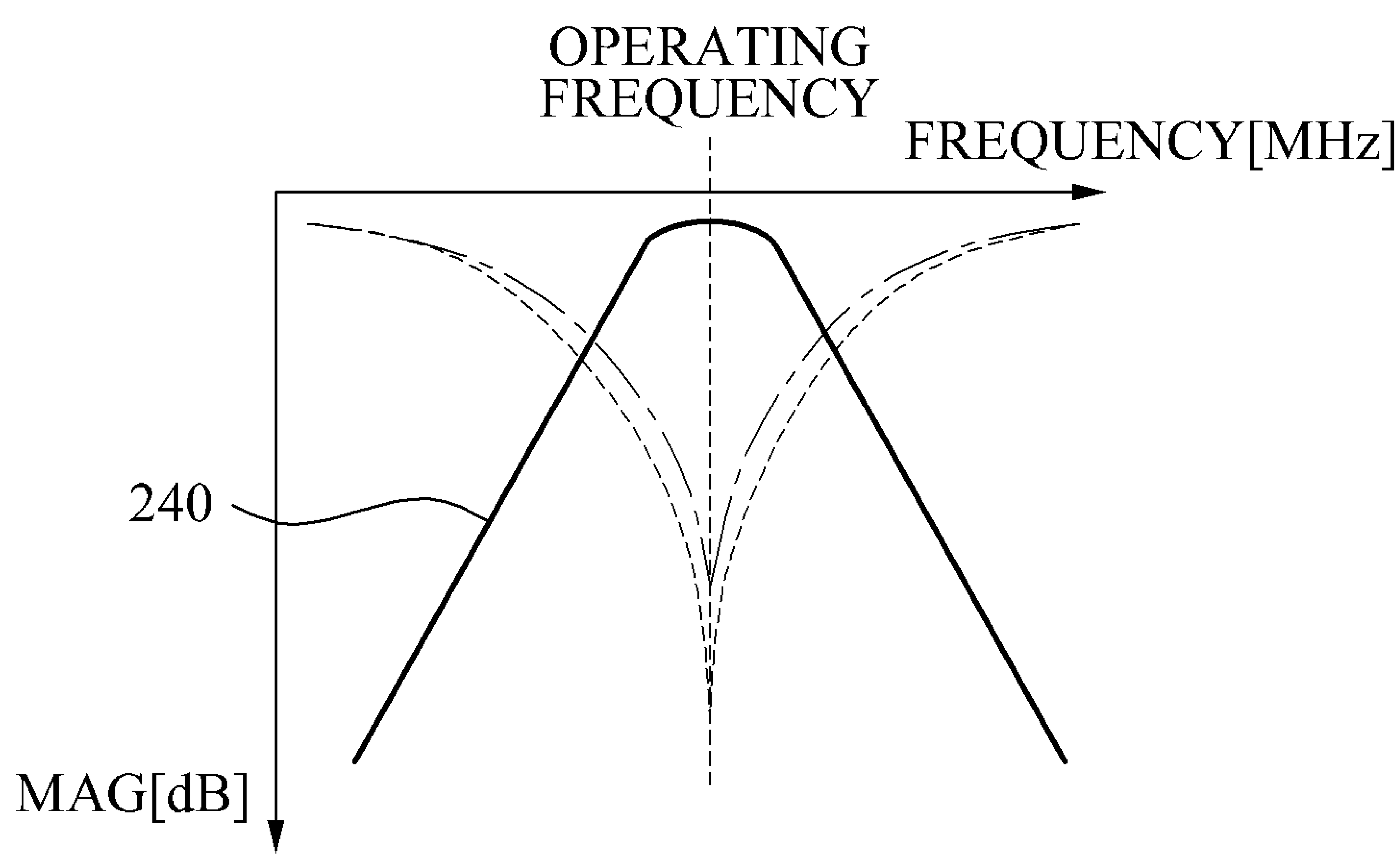


FIG. 2C

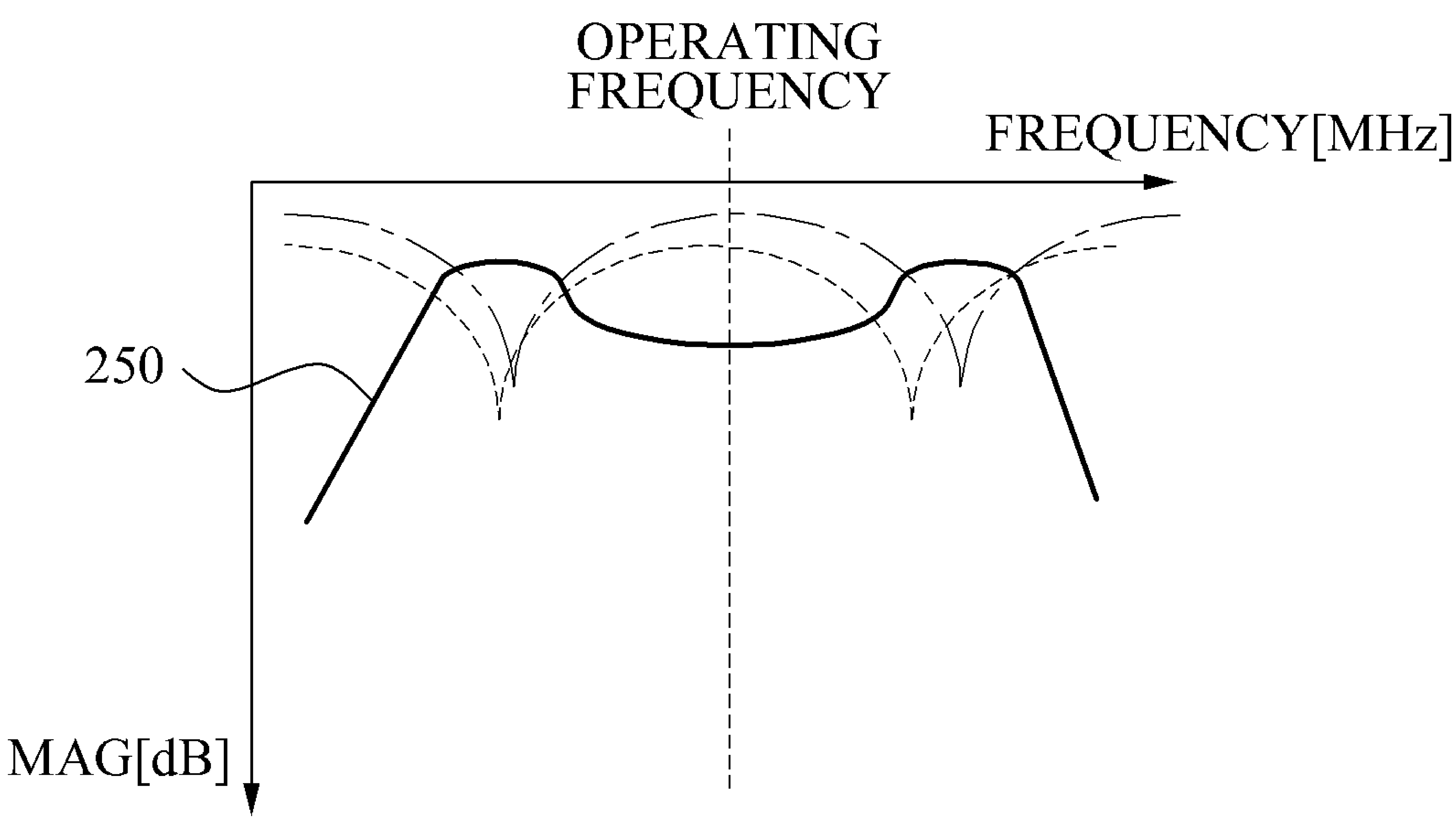


FIG. 3

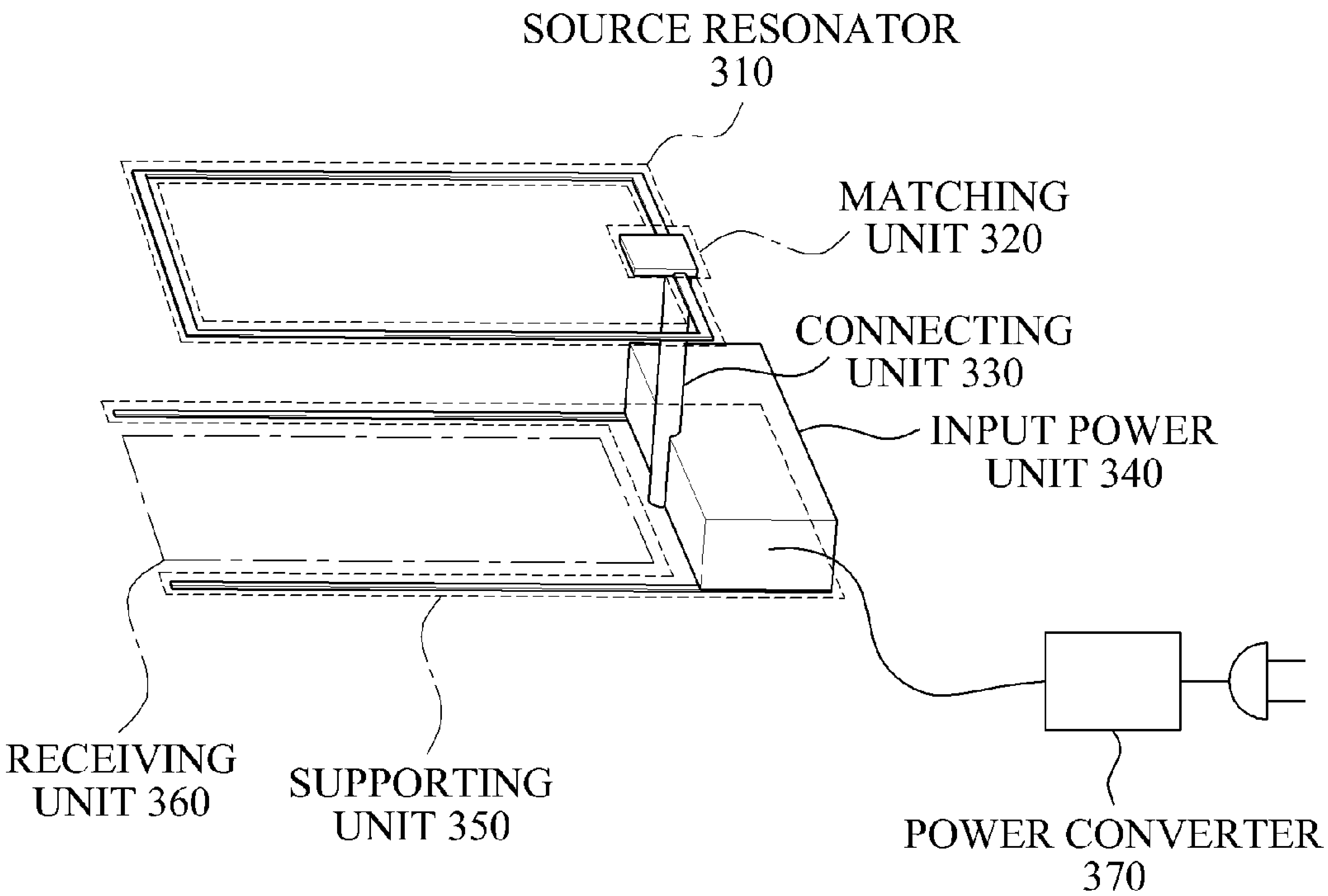

SOURCE RESONATOR
310
MATCHING
UNIT 320
CONNECTING
UNIT 330
INPUT POWER
UNIT 340
RECEIVING
UNIT 360
SUPPORTING
UNIT 350
POWER CONVERTER
370

FIG. 4

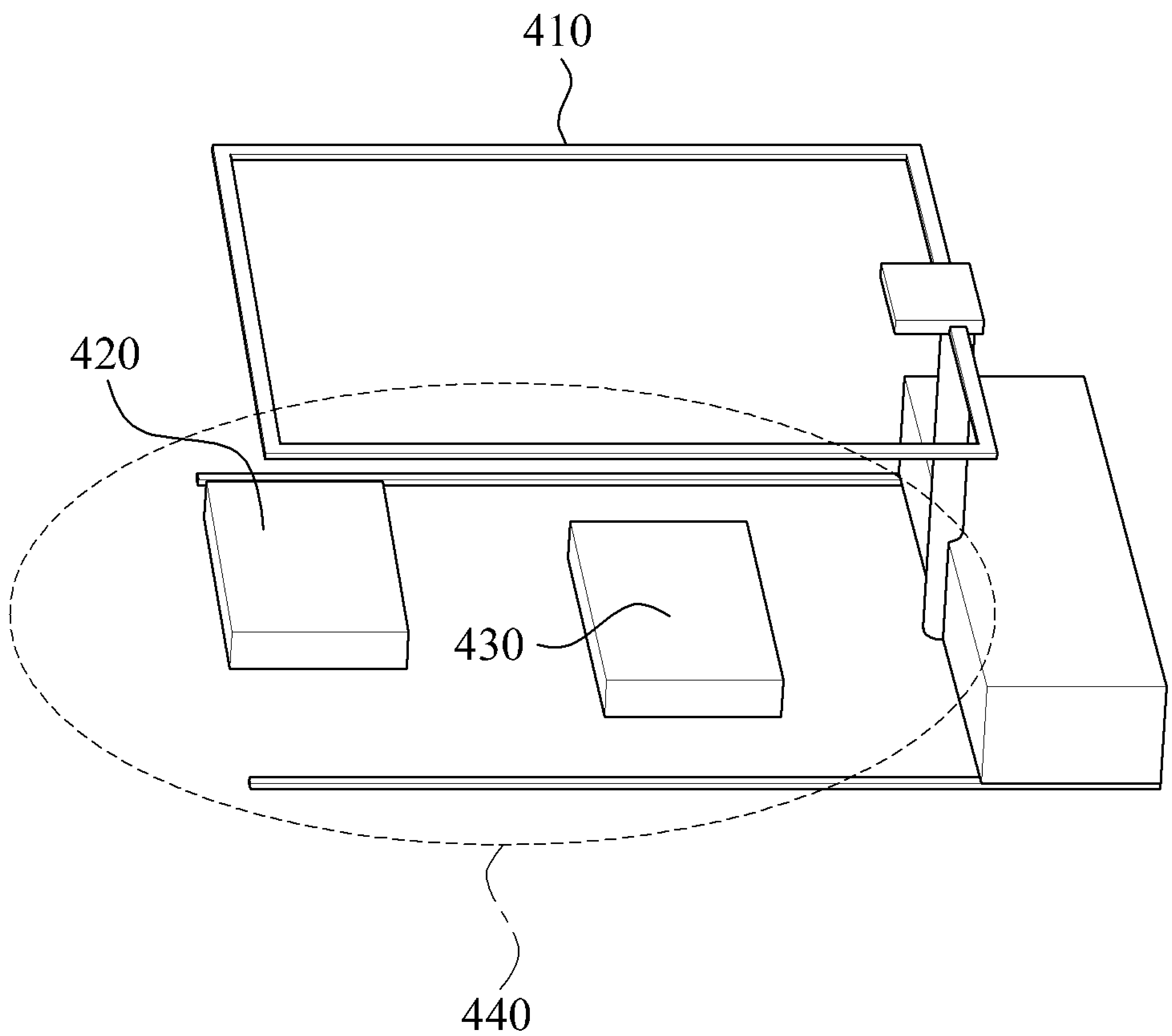


FIG. 5

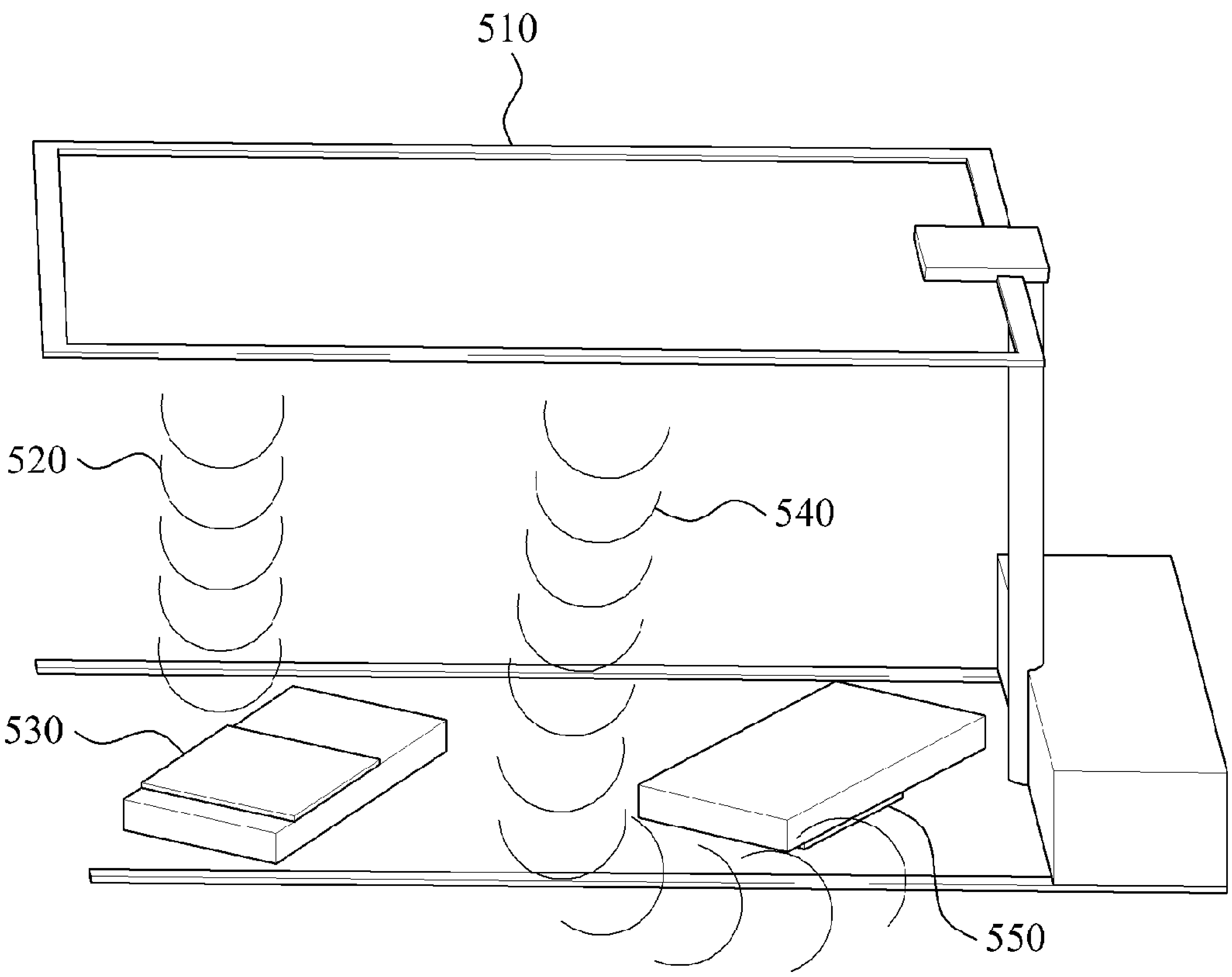


FIG. 6

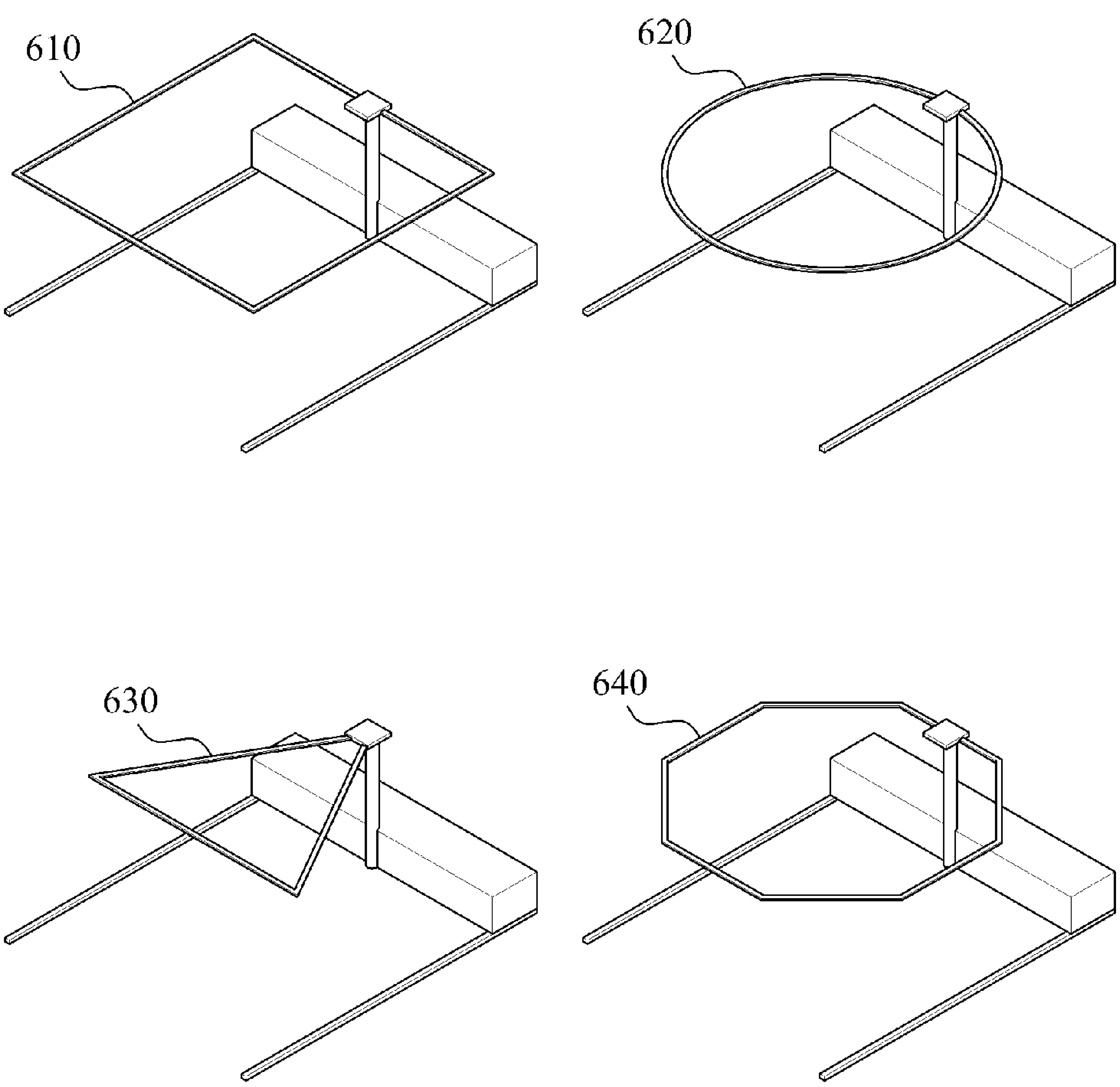


FIG. 7

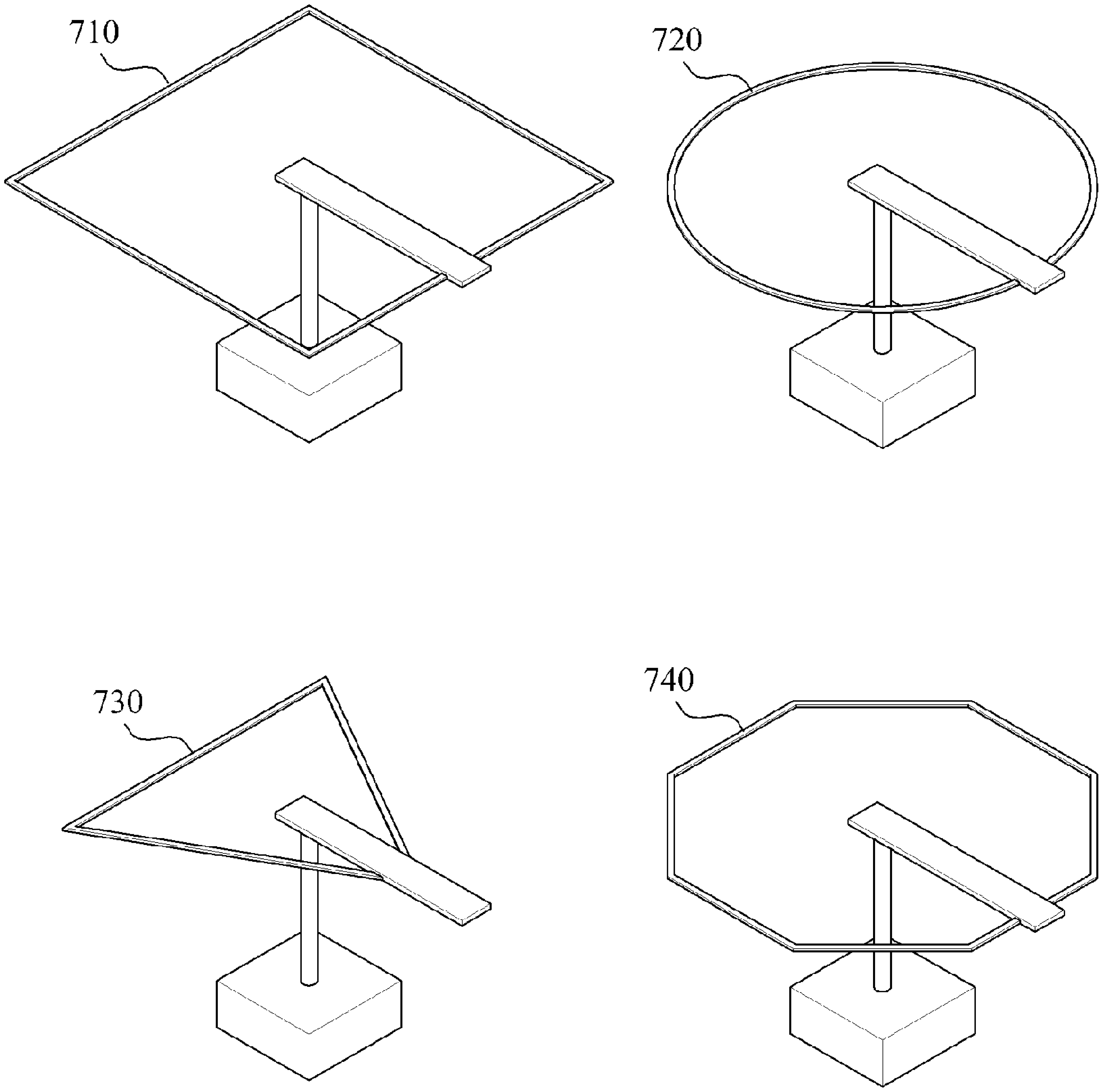


FIG. 8

800

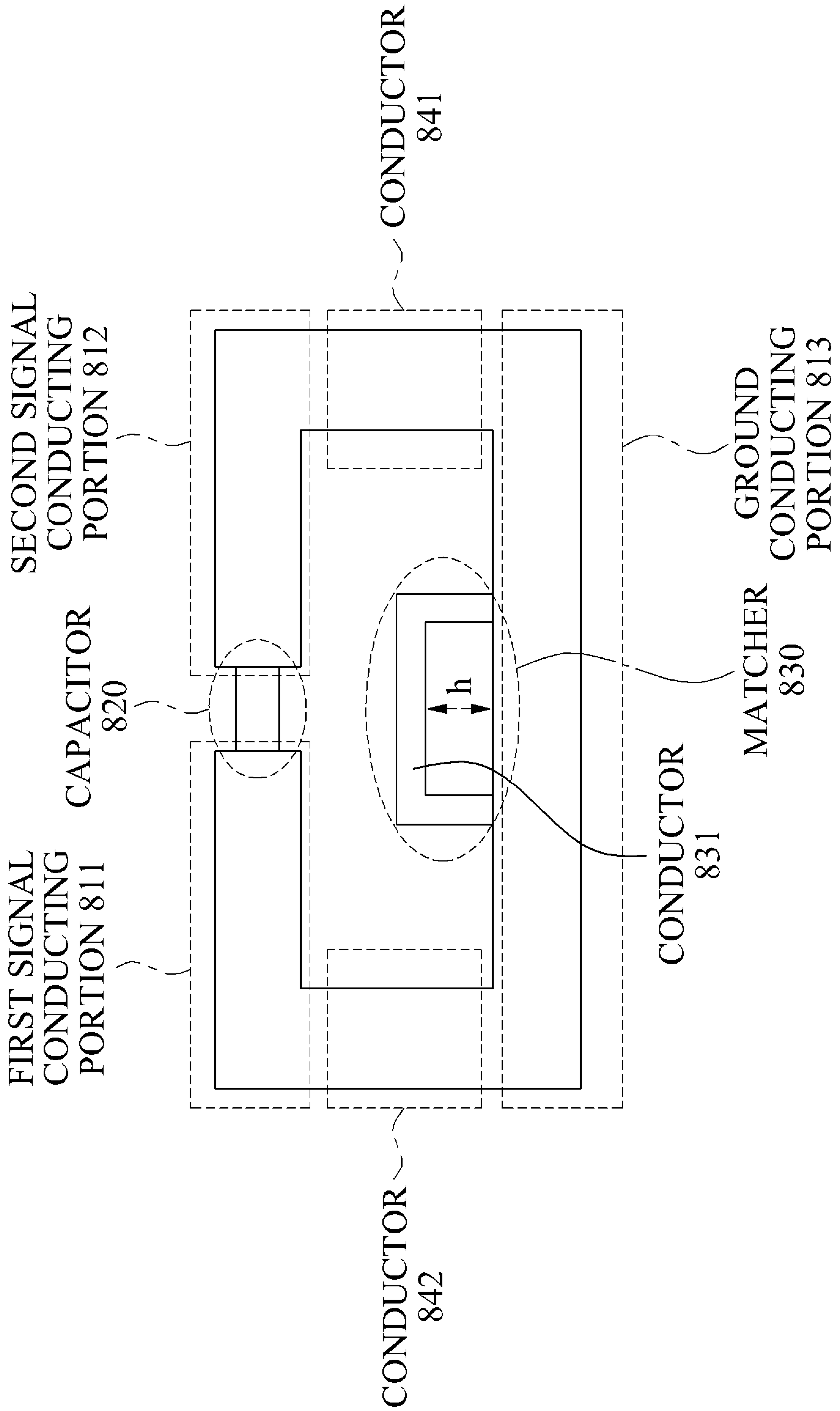

CONDUCTOR 841
SECOND SIGNAL CONDUCTING PORTION 812
GROUND CONDUCTING PORTION 813
CAPACITOR 820
MATCHER 830
h
CONDUCTOR 831
FIRST SIGNAL CONDUCTING PORTION 811
CONDUCTOR 842

FIG. 9

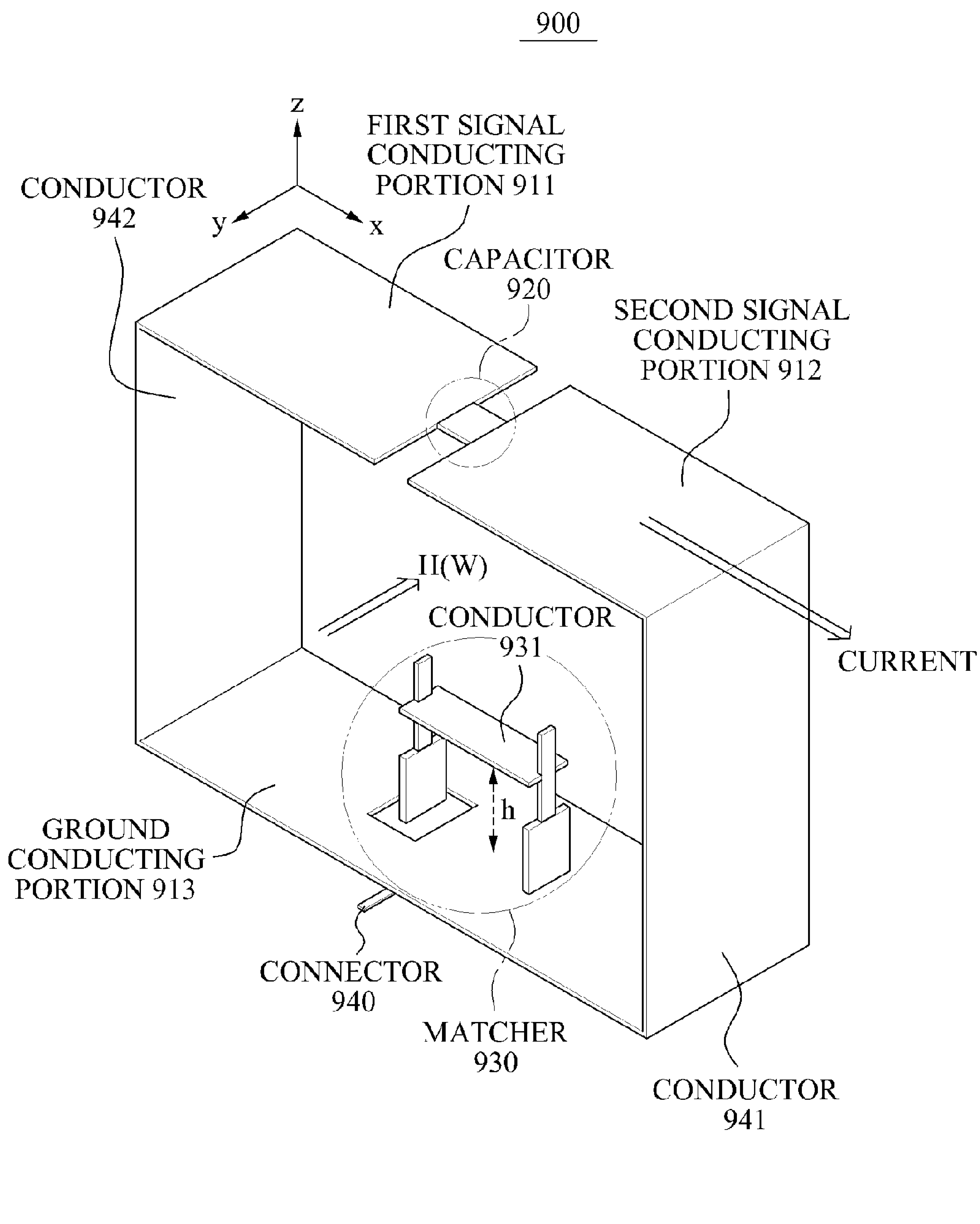

900
z
y
x
FIRST SIGNAL CONDUCTING PORTION 911
CONDUCTOR 942
CAPACITOR 920
SECOND SIGNAL CONDUCTING PORTION 912
H(W)
CONDUCTOR 931
CURRENT
h
GROUND CONDUCTING PORTION 913
CONNECTOR 940
MATCHER 930
CONDUCTOR 941

FIG. 10

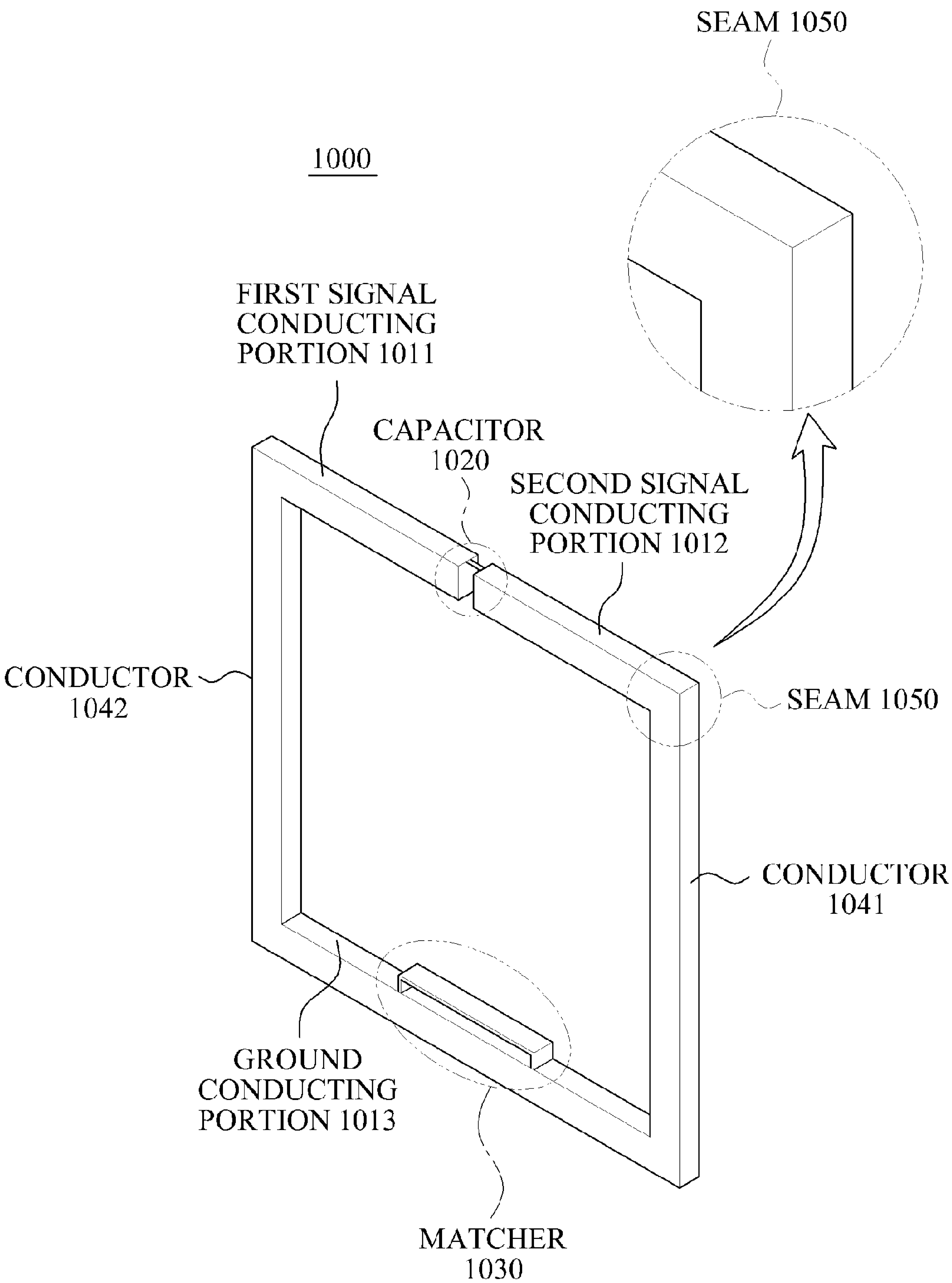

SEAM 1050
1000
FIRST SIGNAL CONDUCTING PORTION 1011
CAPACITOR 1020
SECOND SIGNAL CONDUCTING PORTION 1012
CONDUCTOR 1042
SEAM 1050
CONDUCTOR 1041
GROUND CONDUCTING PORTION 1013
MATCHER 1030

FIG. 11

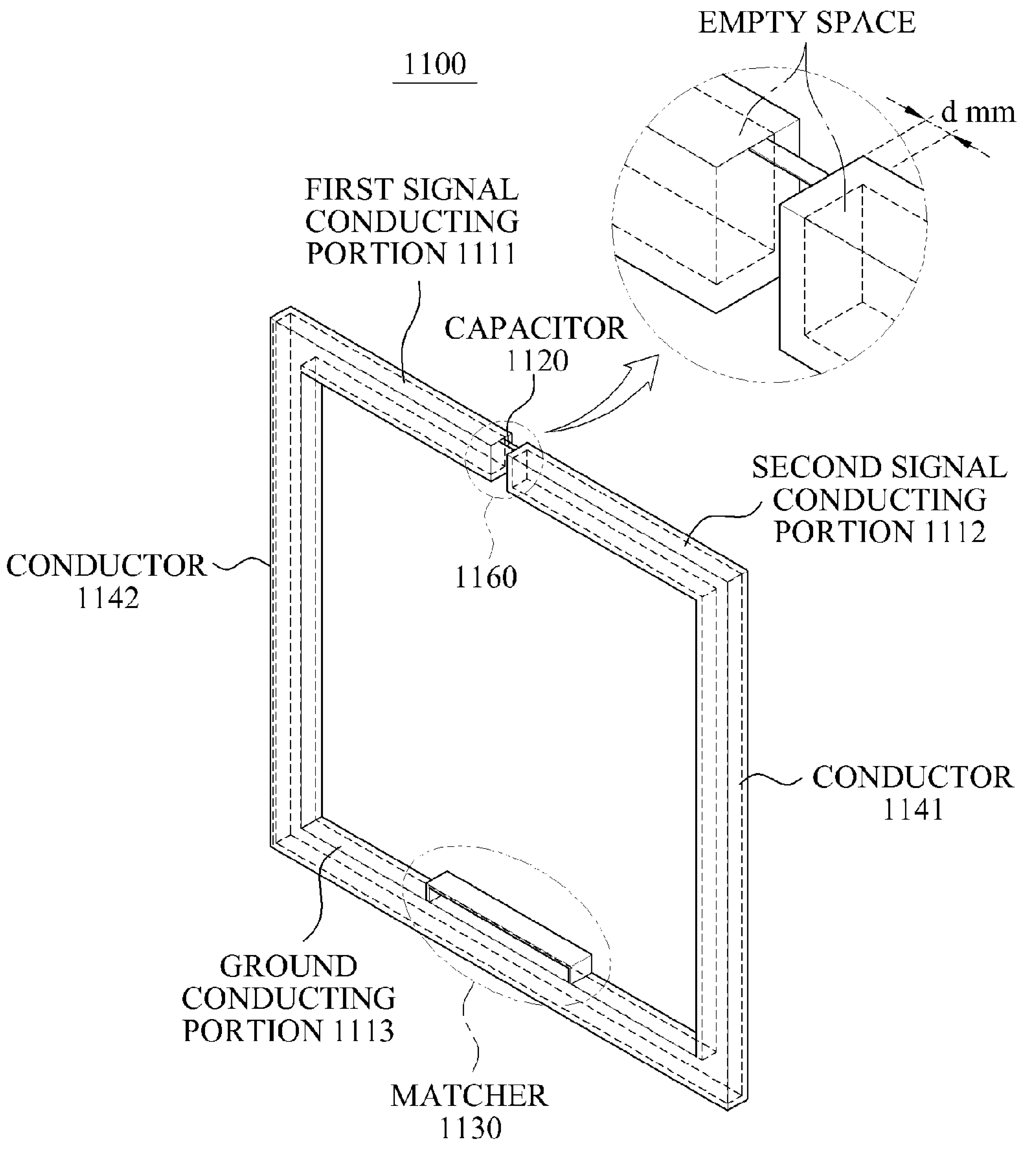

1100
EMPTY SPACE
d mm
FIRST SIGNAL CONDUCTING PORTION 1111
CAPACITOR 1120
SECOND SIGNAL CONDUCTING PORTION 1112
CONDUCTOR 1142
1160
CONDUCTOR 1141
GROUND CONDUCTING PORTION 1113
MATCHER 1130

FIG. 12

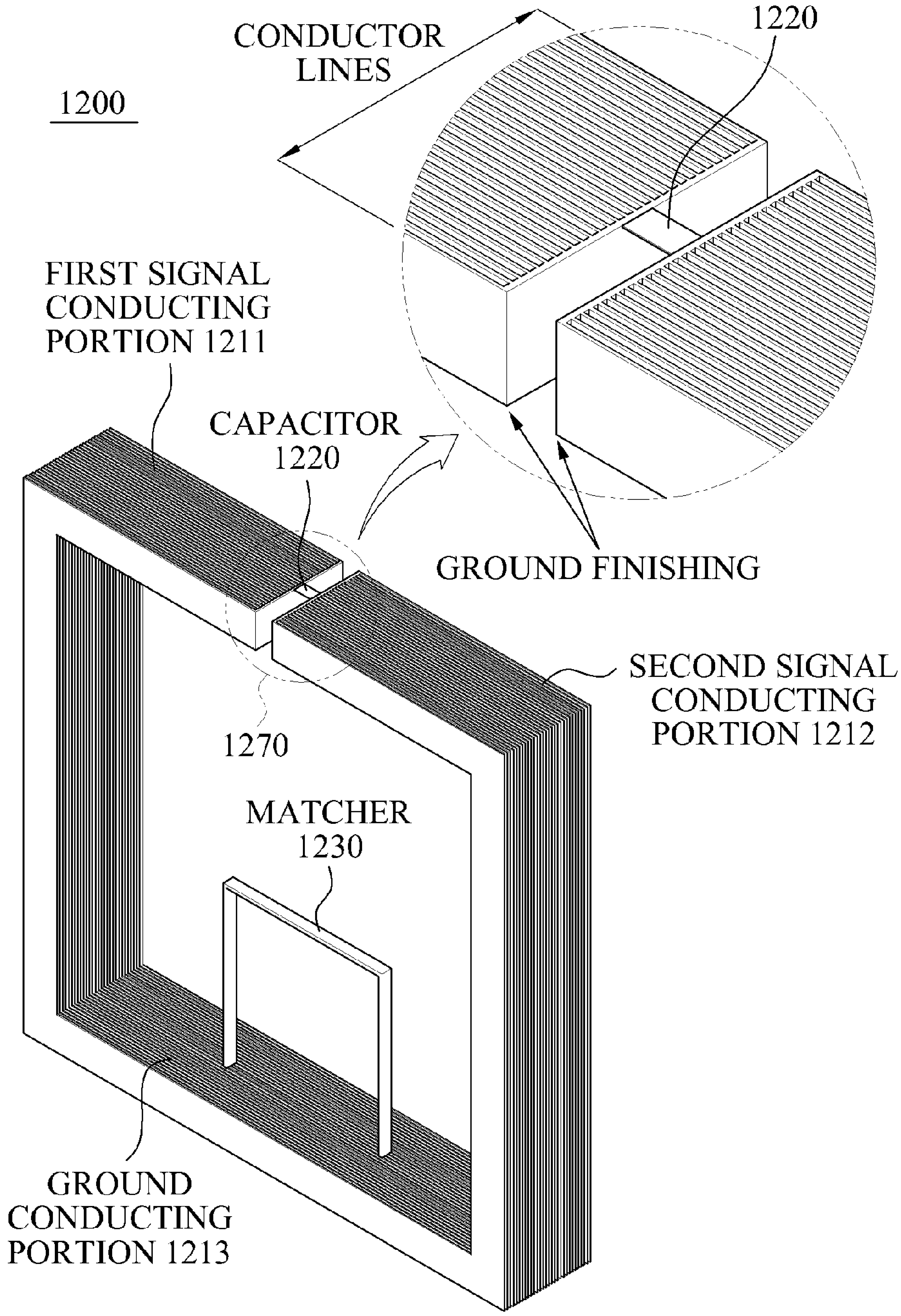

CONDUCTOR LINES
1220
1200
FIRST SIGNAL CONDUCTING PORTION 1211
CAPACITOR 1220
GROUND FINISHING
SECOND SIGNAL CONDUCTING PORTION 1212
1270
MATCHER 1230
GROUND CONDUCTING PORTION 1213

FIG. 13

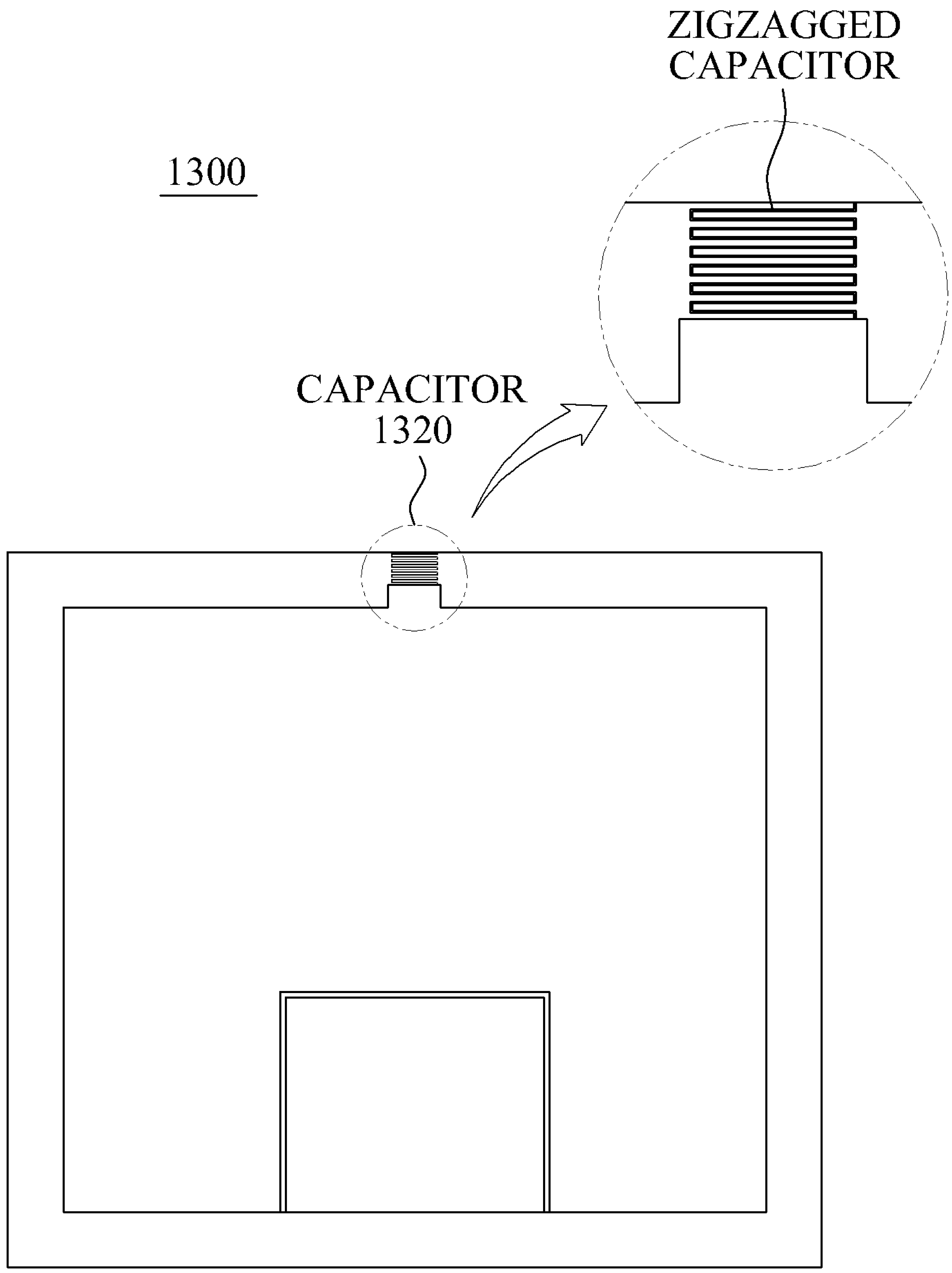


FIG. 14A

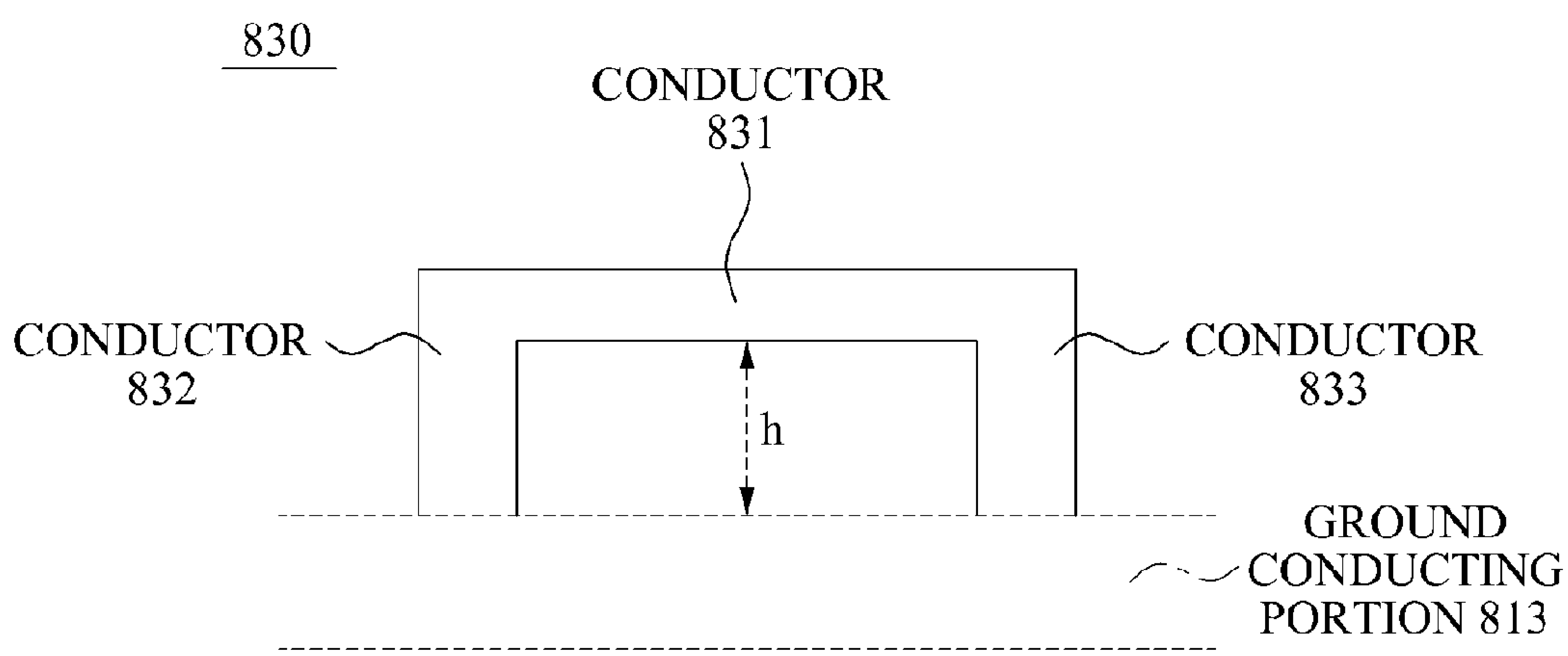

830
CONDUCTOR 831
CONDUCTOR 832
CONDUCTOR 833
h
GROUND CONDUCTING PORTION 813

FIG. 14B

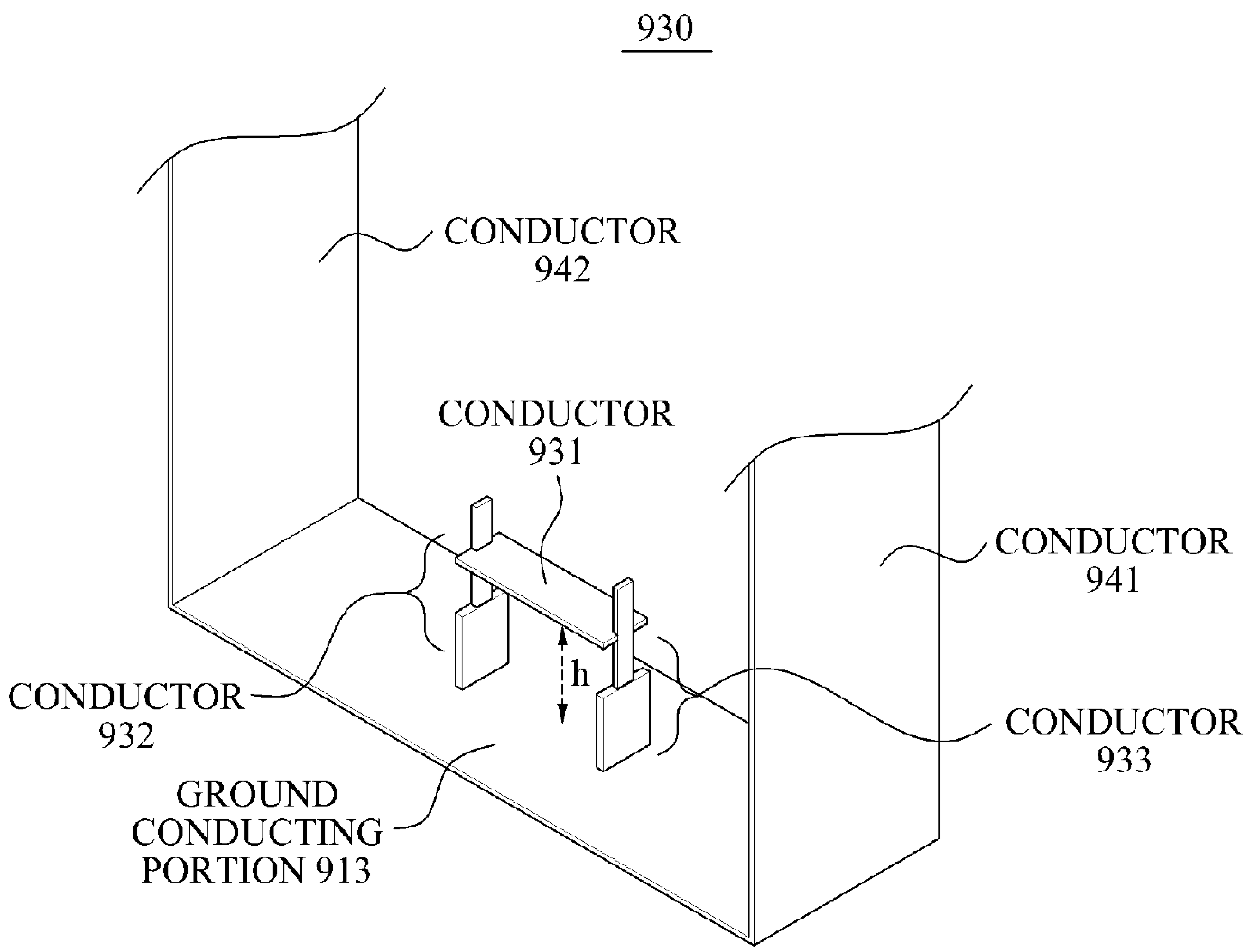
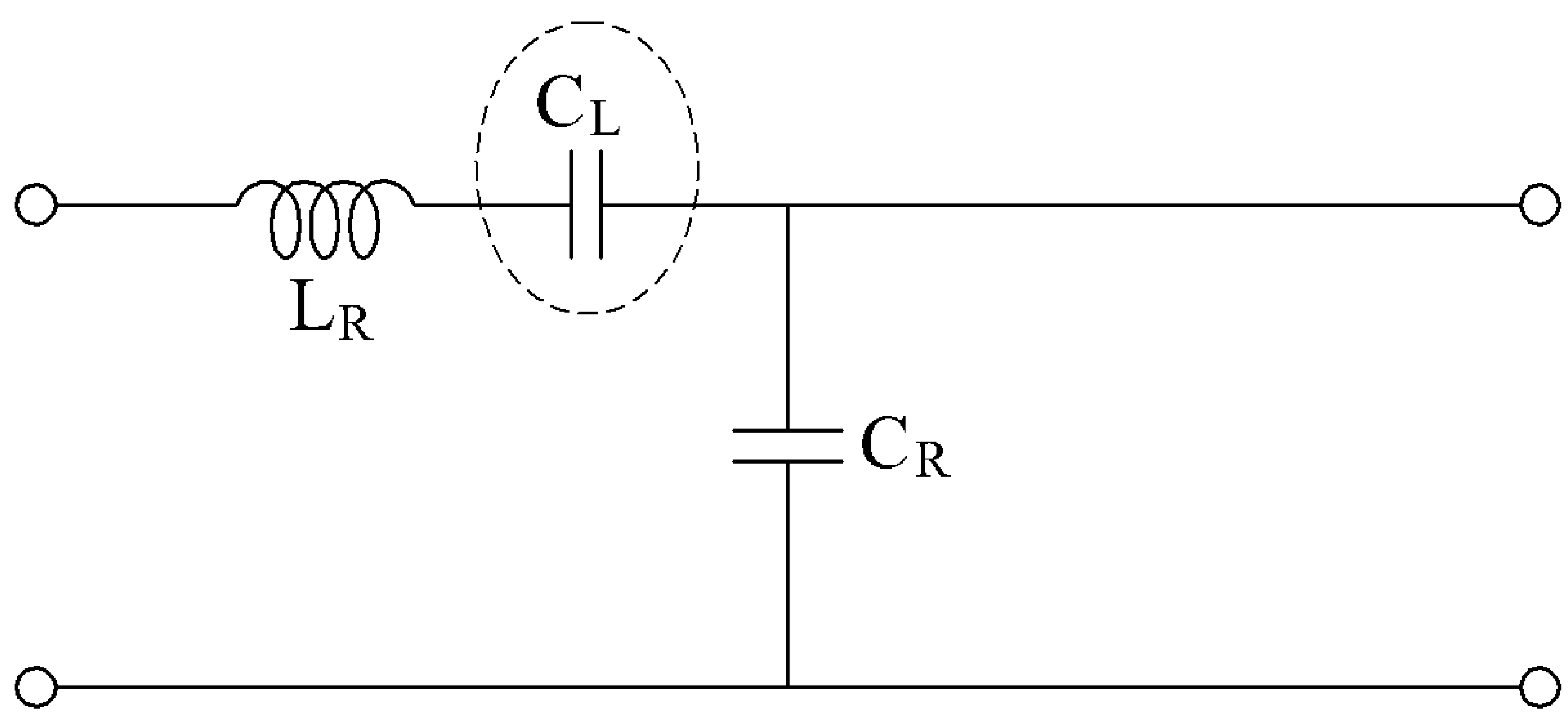

930
CONDUCTOR 942
CONDUCTOR 931
CONDUCTOR 941
CONDUCTOR 932
h
CONDUCTOR 933
GROUND CONDUCTING PORTION 913

FIG. 15



$$\omega_{MZR} = \frac{1}{\sqrt{L_R C_L}}$$

ROOF TYPE CHARGING APPARATUS USING RESONANT POWER TRANSMISSION

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims the benefit under 35 U.S.C. §119 (a) of Korean Patent Application No. 10-2010-0087939, filed on Sep. 8, 2010, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference for all purposes.

TECHNICAL FIELD

The following description relates to apparatuses and method for charging a multi-target device, while transmitting a resonance power.

BACKGROUND

As demand for portable electrical devices has increased, use of wired power supplies has become inconvenient. Studies on wireless power transmission have been conducted to overcome inconveniences of wired power supplies and the limited capacity of conventional batteries. Commonly used mobile devices may perform wireless charging based on an induction scheme that uses a frequency, for example, ranging from dozens of kilohertz (kHz) to hundreds of kHz. The induction scheme may be efficient in wireless power transmission. However, to perform conventional wireless power transmission, induction coils are close to each other, and a location of a center of a wireless power transmission coil may be the same as a wireless power reception coil. Thus, the induction scheme may have a limited charging scope, and may not be able to perform charging that simultaneously charges a plurality of mobile devices using a single wireless power transmission coil.

SUMMARY

According to an aspect, a roof-type charging apparatus using resonance power transmission comprises: a source resonance unit configured to transmit resonance power including a source resonator having a generally planar loop configuration and defining a space therein; a receiving unit configured to receive the resonance power transmitted from the source resonator; and a connecting unit configured to separate the source resonator and the receiving unit by a predetermined distance.

According to an aspect, the source resonator and the receiving unit are positioned generally parallel with respect to one another.

According to an aspect, the source resonator is one of: square-shaped, rectangular-shaped, circle-shaped, oval-shaped, elliptical-shaped, triangle-shaped, octagon-shaped and polygon-shaped.

According to an aspect, the source resonator defines an effective charging radius of the source resonator.

According to an aspect, a target resonator that receives the resonance power transmission is positioned inside the effective charging radius of the source resonator.

According to an aspect, the apparatus further comprises: an input power unit configured to generate a resonance power based on a resonance frequency, and to provide the resonance power to the source resonator.

According to an aspect, the input power unit is located below the space defined by the source resonator.

According to an aspect, the apparatus further comprises: a matching unit configured to match a coupling impedance of the source resonator and a target resonator that receives the resonance power transmission.

According to an aspect, the matching unit is positioned in the space defined by the source resonator.

According to an aspect, the source resonance unit includes a frame configured to connect the source resonator to the connecting unit.

According to an aspect, the apparatus further comprises: a power converter configured to convert alternating current (AC) power of a voltage source to a direct current (DC) power.

According to an aspect, the connecting unit comprises a hollow cylinder, and a cable passing through the inside of the hollow cylinder.

According to an aspect, the hollow cylinder is formed of an insulative material.

According to an aspect, the predetermined distance is adjustable thereby providing impedance matching between the source resonator and a target resonator that receives the resonance power transmission.

According to an aspect, the source resonance unit includes an extension controller configured to adjust an effective charging radius of the source resonator.

According to an aspect, the apparatus further comprises: a supporting unit configured to support the apparatus.

According to an aspect, a method of transmitting resonance power comprises: transmitting resonance power using a source resonator having a generally planar loop configuration defining a space therein; and receiving with a receiving unit the resonance power transmitted from the source resonator, wherein the source resonator and the receiving unit are separated by a predetermined distance.

According to an aspect, the source resonator is one of: square-shaped, rectangular-shaped, circle-shaped, triangle-shaped, octagon-shaped and polygon-shaped.

According to an aspect, the source resonator defines an effective charging radius of the source resonator.

According to an aspect, a target resonator that receives the resonance power transmission is positioned inside the effective charging radius of the source resonator.

According to an aspect, the method further comprises: adjusting the predetermined distance to provide impedance matching between the source resonator and a target resonator that receives the resonance power transmission.

According to an aspect, the method further comprises: adjusting an effective charging radius of the source resonator.

According to an aspect, a roof-type charging apparatus using resonance power transmission comprises: a source resonance unit configured to transmit resonance power including a source resonator having a generally planar loop configuration and defining a space therein; a receiving unit configured to receive the resonance power transmitted from the source resonator; a matching unit located in a predetermined area of a frame of the source resonator and configured to match, to a predetermined value, a coupling impedance between the source resonator and at least one target resonator that receives the resonance power transmission; an input power unit configured to generate resonance power based on a resonance frequency, and to provide the resonance power to the source resonator; a connecting unit configured to separate the source resonator and the receiving unit by a predetermined distance; and a supporting unit connected to the input power unit and configured to support the roof-type charging apparatus.

According to an aspect, a source resonance unit configured to transmit resonance power comprises: a source resonator having a generally planar loop configuration and defining a space therein.

Other features and aspects may be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a wireless power transmission system.

FIGS. **2**A through **2**C relate to a pad-type charging apparatus using resonance power transmission.

FIG. **3** is a diagram illustrating a roof-type charging apparatus using resonance power transmission.

FIG. **4** is a diagram illustrating a location where a target device is charged in a roof-type charging apparatus using resonance power transmission.

FIG. **5** is a diagram illustrating resonance power transmission based on a location of a target resonator in a resonance power receiver.

FIG. **6** is a diagram illustrating various examples of source resonators.

FIG. **7** is a diagram illustrating various examples of roof-type charging apparatuses which use resonance power transmission.

FIG. **8** is a diagram illustrating a resonator having a two-dimensional (2D) structure.

FIG. **9** is a diagram illustrating a resonator having a three-dimensional (3D) structure.

FIG. **10** is a diagram illustrating a resonator for wireless power transmission configured as a bulky type.

FIG. **11** is a diagram illustrating a resonator for wireless power transmission configured as a hollow type.

FIG. **12** is a diagram illustrating a resonator for wireless power transmission using a parallel-sheet.

FIG. **13** is a diagram illustrating a resonator for wireless power transmission, the resonator including a distributed capacitor.

FIG. **14**A is a diagram illustrating a matcher used by a 2D resonator.

FIG. **14**B is a diagram illustrating a matcher used by a 3D resonator.

FIG. **15** is a diagram illustrating one equivalent circuit of the resonator for wireless power transmission illustrated in FIG. **8**.

Throughout the drawings and the detailed description, unless otherwise described, the same drawing reference numerals should be understood to refer to the same elements, features, and structures. The relative size and depiction of these elements may be exaggerated for clarity, illustration, and convenience.

DETAILED DESCRIPTION

The following detailed description is provided to assist the reader in gaining a comprehensive understanding of the methods, apparatuses and/or systems described herein. Accordingly, various changes, modifications, and equivalents of the systems, apparatuses and/or methods described herein may be suggested to those of ordinary skill in the art. The progression of processing steps and/or operations described is an example; however, the sequence of and/or operations is not limited to that set forth herein and may be changed as is known in the art, with the exception of steps and/or operations necessarily occurring in a certain order. Also, descriptions of well-known functions and constructions may be omitted for increased clarity and conciseness.

FIG. **1** illustrates a wireless power transmission system.

In one or more embodiments, a wireless power transmitted using the wireless power transmission system may be resonance power. However, it will be appreciated that in other embodiments various other methodologies for electromagnetic power transmission may be used; including wired and wireless technologies, for instance.

The wireless power transmission system may have a source-target structure including a source and a target. As shown in FIG. **1**, the wireless power transmission system may include a resonance power transmitter **110** corresponding to the source and a resonance power receiver **120** corresponding to the target being configured for the wireless transmission of electromagnetic energy.

The resonance power transmitter **110** may include a source unit **111** and a source resonator **115**. The source unit **111** may be configured to receive energy from an external voltage supplier to generate resonance power. The resonance power transmitter **110** may further include a matching control **113** to perform resonance frequency or impedance matching for resonance power transmission via an inductive or magnetic coupling **101**.

The source unit **111** may include, for example, one or more of: an alternating current (AC)-to-AC (AC/AC) converter, an AC-to-direct current (DC) (AC/DC) converter, and/or a (DC/AC) inverter. The AC/AC converter may adjust, to a desired level, a signal level of an AC signal input from an external device. The AC/DC converter may output a DC voltage at a predetermined level by rectifying an AC signal output from the AC/AC converter. The DC/AC inverter may be configured to generate an AC signal, for example, of a few megahertz (MHz) to tens of MHz band by quickly switching a DC voltage output from the AC/DC converter. AC voltage output having other frequencies is also possible.

The matching control **113** may be configured to set a resonance bandwidth of the source resonator **115**, an impedance matching frequency of the source resonator **115** or both. The matching control **113** may include a source resonance bandwidth setting unit and/or a source matching frequency setting unit. The source resonance bandwidth setting unit may set the resonance bandwidth of the source resonator **115**, for example. The source matching frequency setting unit may be configured to set the impedance matching frequency of the source resonator **115**. In various implementations, a Q-factor of the source resonator **115** may be determined, for instance, based on setting of the resonance bandwidth of the source resonator **115** or setting of the impedance matching frequency of the source resonator **115**.

The source resonator **115** may be configured to transfer electromagnetic energy wirelessly to a target resonator **121**. For example, in one or more embodiments, the source resonator **115** may be configured to transfer the resonance power to the resonance power receiver **120** through inductive coupling **101**. The source resonator **115** may be configured to resonate within the set resonance bandwidth.

As shown in FIG. **1**, the source resonator **115** may be configured to convert electrical energy into magnetic energy for wireless transmission of power through the inductive coupling **101** to the target resonator **121**. The target resonator **121** in turn receives magnetic energy and converts the received magnetic energy into corresponding electrical energy. The source resonator **115** and the target resonator **121** forming the inductive coupling **101** may be configured, for example, in a helix coil structured resonator, a spiral coil structured resonator, a meta-structured resonator, or the like. As such, the resonator power transmitter **110** and the resonance power receiver may be physically spaced apart to permit power transmission inductively without any wired connections there between.

The resonance power receiver **120** may include the target resonator **121**, a matching control **123** configured to perform resonance frequency or impedance matching, and a target unit **125** configured to transfer the received resonance power to a load.

The target resonator **121** may be configured to receive the electromagnetic energy from the source resonator **115**. The target resonator **121** may also be configured to resonate within the set resonance bandwidth.

The matching control **123** may be configured to set at least one of a resonance bandwidth of the target resonator **121** and an impedance matching frequency of the target resonator **121**. In various implementations, the matching control **123** may include a target resonance bandwidth setting unit and/or a target matching frequency setting unit. The target resonance bandwidth setting unit may set the resonance bandwidth of the target resonator **121** with the target matching frequency setting unit configured to set the impedance matching frequency of the target resonator **121**. In some implementations, a Q-factor of the target resonator **121** may be determined based on setting of the resonance bandwidth of the target resonator **121** or setting of the impedance matching frequency of the target resonator **121**.

The target unit **125** may be configured to transfer the received resonance power to the device (load). The target unit **125** may include, for example, an AC/DC converter and/or a DC/DC converter. In some implementations, the AC/DC converter may generate a DC voltage by rectifying an AC signal transmitted from the source resonator **115** to the target resonator **121**. And the DC/DC converter may supply a rated voltage to a device or the load by adjusting a voltage level of the DC voltage.

Referring to FIG. **1**, a process of controlling the Q-factor may include setting the resonance bandwidth of the source resonator **115** and the resonance bandwidth of the target resonator **121**, and transferring the electromagnetic energy from the source resonator **115** to the target resonator **121** through inductive coupling **101** between the source resonator **115** and the target resonator **121**. The resonance bandwidth of the source resonator **115** may be set, for instance, to be wider or narrower than the resonance bandwidth of the target resonator **121**. Accordingly, an unbalanced relationship between a BW-factor of the source resonator **115** and a BW-factor of the target resonator **121** may be maintained by setting the resonance bandwidth of the source resonator **115** to be wider or narrower than the resonance bandwidth of the target resonator **121**.

In wireless power transmission employing a resonance scheme, the resonance bandwidth can be an important factor. For example, with the Q-factor (considering, for instance, one or more of: a change in a distance between the source resonator **115** and the target resonator **121**, a change in the resonance impedance, impedance mismatching, a reflected signal, and/or the like), denoted as Qt, it has been found that Qt may have an inverse-proportional relationship with the resonance bandwidth, as given by Equation 1.

$$\frac{\Delta f}{f_0} = \frac{1}{Qt} \quad \text{[Equation 1]}$$

-continued

$$= \Gamma_{S,D} + \frac{1}{BW_S} + \frac{1}{BW_D}$$

In Equation 1, f_0 denotes a central frequency, Δf denotes a change in a bandwidth, $\Gamma_{S,D}$ denotes a reflection loss between the source resonator **115** and the target resonator **121**, BWs denotes the resonance bandwidth of the source resonator **115**, and BW_D denotes the resonance bandwidth of the target resonator **121**. The BW-factor may indicate either 1/BWs or $1/BW_D$, for example,

Due to one or more external factors including, for example, a change in the distance between the source resonator **115** and the target resonator **121**, a change in a location of at least one of the source resonator **115** and the target resonator **121**, or the like, impedance mismatching between the source resonator **115** and the target resonator **121** can occur. The impedance mismatching may be a direct cause in decreasing an efficiency of power transfer. Thus, when a reflected wave corresponding to a transmission signal that is partially reflected and returned is detected, the matching control **113** may be configured to determine whether an impedance mismatching has occurred, and may also be configured to perform impedance matching. The matching control **113**, for instance, may change a resonance frequency by detecting a resonance point through a waveform analysis of the reflected wave. In one implementation, the matching control **113** may determine, as the resonance frequency to be a frequency having a minimum amplitude in the waveform of the reflected wave.

An electromagnetic characteristic of many materials found in nature is that they have a unique magnetic permeability or a unique permittivity. Most materials typically have a positive magnetic permeability or a positive permittivity. Thus, for these materials, a right hand rule may be applied to an electric field, a magnetic field, and a pointing vector and thus, the corresponding materials may be referred to as right handed materials (RHMs).

On the other hand, a material having a magnetic permeability or a permittivity which is not ordinarily found in nature or is artificially-designed (or man-made) may be referred to herein as a "metamaterial." Metamaterials may be classified into an epsilon negative (ENG) material, a mu negative (MNG) material, a double negative (DNG) material, a negative refractive index (NRI) material, a left-handed (LH) material, and the like, based on a sign of the corresponding permittivity or magnetic permeability.

One or more of the materials of the embodiments disclosed herein may be metamaterials. The magnetic permeability may indicate a ratio between a magnetic flux density occurring with respect to a given magnetic field in a corresponding material and a magnetic flux density occurring with respect to the given magnetic field in a vacuum state. The magnetic permeability and the permittivity, in some embodiments, may be used to determine a propagation constant of a corresponding material in a given frequency or a given wavelength. An electromagnetic characteristic of the corresponding material may be determined based on the magnetic permeability and the permittivity. According to an aspect, the metamaterial may be easily disposed in a resonance state without significant material size changes. This may be practical for a relatively large wavelength area or a relatively low frequency area, for instance.

FIG. **2**A illustrates a diagram of a pad-type charging apparatus using resonance power transmission including a source resonator **210** and a target resonator **220**.

A wireless charger **200** employs a "pad-type" charging scheme where a mobile device is placed on a charging pad to wirelessly charge the mobile device based on a resonance power transmission scheme, in the same manner as the induction charging scheme. Wireless charging based on the resonance power transmission scheme may use a near field magnetic coupling scheme and thus, when the distance between the source resonator **210** and the target resonator **220** is close, for example, less than or equal to 1 cm, an impedance may rapidly vary.

When the distance between the source resonator **210** and the target resonator **220** is less than or equal to several millimeters, an impedance may widely and rapidly vary and thus, an efficiency of a resonator may decrease in an operating frequency. The wide and rapid change in the impedance may affect an input/output matching of a power amplifier that supplies a wireless power and an input/output matching of a rectifier that converts a received AC power to a DC power. Accordingly, an efficiency of a wireless power transmission system may be deteriorated.

The wide and rapid change in the impedance may be minimized by impedance matching, for example, when a location **230** of the resonator **220** is slightly different from a matching location or when a plurality of target resonators are placed on the charging pad for a multi-target device, the impedance of the resonator may vary again. Therefore, when the resonance power transmission scheme is used, a pad-type wireless charger may not be effective to obtain high wireless power transmission efficiency.

Unlike a conventional induction scheme, a resonance power transmission scheme may perform wireless power transmission even when a distance between a source resonator **210** and a target resonator **220** is more than several dozen centimeters, for instance. Thus, even when a location of a center of the source resonator **210** is different from a location of a center of the target resonator **220**, the wireless power transmission may be effectively performed.

Wireless chargers using resonance power transmission for low-power mobile devices having a power-use level less than or equal to 10 watts (W) have been studied. FIG. **2**B illustrates a plot of transmission efficiency as a function of operation frequency when the distance between the source resonator **210** and the target resonator **220** is greater than or equal to a several dozen centimeters. FIG. **2**C illustrates a plot of transmission efficiency as a function of operation frequency when the distance between the source resonator **210** and the target resonator **220** is less than or equal to several millimeters.

The plot illustrated in FIG. **2**B, shows a transmission efficiency **240** may be highest in an operating frequency where the target resonator **220** and the source resonator **210** perform resonance power transmission. On the other hand, the plot illustrated in FIG. **2**C, shows that a transmission efficiency **250** may be lowest when the distance between the target resonator **220** and the source resonator **210** is less than about several millimeters.

FIG. **3** illustrates a roof-type charging apparatus using resonance power transmission.

As shown, the roof-type charging apparatus using resonance power transmission may include a source resonance unit **310**, a matching unit **320**, a connecting unit **330**, an input power unit **340**, a supporting unit **350**, a receiving unit **360**, and a power converter **370**.

According to an aspect, the charging apparatus may be configured as a "roof-type." The term "roof-type," as used herein, refers to a charging apparatus including one or more resonator sources having a generally planar loop configuration defining a space therein. The resonator source(s) as such may be referred to as a "roof." In some embodiments, the one or more source resonators may be configured as a circular structure, an oval structure, an elliptical structure, a rectangular structure, a square structure, triangular structure, polygonal structure, or the like. An effective charging radius may be defined based on the shape or geometry of the "roof" source resonator. One or more target resonators which are to receive a charge wirelessly, such as, for example, a battery, may be positioned inside the effective charging radius. The target resonators receive power transmission inductively without any wired connections there between.

In the roof-type charging apparatus the source resonators may be spaced apart from the receiving unit. For instance, in some embodiments, the source resonators and the receiving unit may be positioned generally parallel with respect to one another. The distance between the source resonators and the receiving unit may be adjusted to provide impedance matching between the source resonator and a target resonator that receives the resonance power transmission. The connecting unit may be providing between the source resonators and the receiving unit for such purposes.

As shown in FIG. **3**, the source resonator **310** may be generally rectangular or square-shaped. In one implementation, the source resonator **310** may have a size of 20 cm in length and 20 cm in width, for example. The source resonator **310** may be connected to the matching unit **320** and the connecting unit **330**. A predetermined area of the frame of the source resonator may define a space therein and be connected to the matching unit **320** and/or the connecting unit **330**.

The source resonance unit **310** may be configured to transmit a resonance power through magnetic coupling regardless of a location of a resonator included in a resonance power receiver, to the resonance power receiver located in a charging radius of the source resonator. The effective charging radius of the source resonator may be determined based on a shape of the source resonator. Advantageously, the source resonance unit **310** may be configured to transmit the resonance power regardless of whether the source resonator and a target resonator included in the resonance power receiver directly face each other.

In various embodiments, the source resonance unit **310** may include a generally planar source resonator that is square-shaped, rectangular-shaped, circle-shaped, triangle-shaped or polygon-shaped (octagon-shaped shown), for example. Of course, it will be appreciated that other shaped source resonators are also possible.

The source resonance unit **310** may also include an extension controller that controls a charging radius of a terminal by controlling a size of the source resonator. The extension controller may be configured to charge or control the size of the source resonator and thus, may increase efficiency in transmitting a resonance power to the terminal in the charging radius. In addition, the extension controller may control the size of the source resonator, and may control the charging radius and thus, may charge multiple terminals. For example, the extension controller may rotate the source resonance unit **310** using the connecting unit **330** as an axis. When the source resonance unit **310** rotates, the charging radius where the terminal is charged may be extended.

The matching unit **320** may be located in a predetermined area of the frame of the source resonator, and may be configured to match, to a predetermined value, a coupling impedance between the source resonator and at least one target resonator. For example, the matching unit **320** may substantially match the coupling impedance between the source resonator and the at least one target resonator. The coupling impedance may be match to within about 50 ohms, in some implementations. The matching unit **320** may control the connecting unit **330** to control a distance between the source resonator and the at least one target resonator for coupling impedance matching. And the matching unit **320** may be connected to the source resonator, and may be located in and occupy a predetermined area inside or outside the roof of the source resonator. Also the matching unit **320** may be connected to the connecting unit **330**. For example, the matching unit **320** may be located in an upper part of the connecting unit **330**.

The connecting unit **330** may connect the source resonator to the input power unit **340** to enable the input power unit **340** to be separated by a predetermined length away from the source resonator. As such, the connecting unit **330** may enable the source resonator and the matching unit **320** to be separated by the predetermined distance or length away from a ground. In some implementations, the predetermined length may be several dozen centimeters, for instance. The connecting unit **330** may connect the source resonance unit **310** to the input power unit **340**.

The connecting unit **330** may be hollow cylinder, having a wireless frequency cable passes through the inside of the hollow cylinder. For example, the connecting unit **330** may be manufactured or otherwise formed as a plastic column of about 10 cm to 20 cm in length. And a radio frequency (RF) cable may pass through the inside the hollow cylinder to the source resonator from a power amplifier, for example. A distance or height of the connecting unit **330** may be controlled for impedance matching between the source resonator and the at least one target resonator. The connecting unit **330** may be manufactured from an insulative material, for example, plastic, to avoid affecting the resonance frequency.

Input power unit **340** may be configured to generate the resonance power based on the resonance frequency, and may provide the resonance power to the source resonator. For example, the input power unit **340** may include a frequency generator and a power amplifier. The frequency generator may generate an operating frequency so that the source resonator and the at least one target resonator perform resonance power transmission. In various implementations, the operating frequency may be a resonance frequency when an impedance of the source resonator and an impedance of the at least one target resonator are matched.

The power amplifier may be configured to amplify the resonance power in response to a request of the at least one target resonator in the operating frequency. The amplified resonance power may be provided to the source resonator. The input power unit **340** may be connected to the connecting unit **330**. For example, the input power unit **340** may include the frequency generator and the power amplifier and thus, a weight of the input power unit **340** may comprise a significant portion of a weight of the roof-type charging apparatus using the resonance power transmission.

The supporting unit **350** may be connected to the input power unit **340** and thus, may support the roof-type charging apparatus using the resonance power transmission. The supporting unit **350** may support the roof-type charging apparatus to prevent the roof-type charging apparatus using the resonance power transmission from falling over. For instance, the supporting unit **350** may be connected to the input power unit **340** and thus, may prevent a center of gravity of the roof-type charging apparatus using the resonance power transmission from being at the front or rear of the roof-type charging apparatus. In one implementation, the supporting unit **350** may be configured as a stand. The supporting unit **350** may be manufactured to be thin to prevent affecting the resonance frequency. The supporting unit **350** may be formed of an insulative material, for example, plastic, to avoid affecting the resonance frequency.

The receiving unit **360** may be located in parallel with the source resonator and may receive the resonance power from the source resonator through magnetic coupling. The resonance power receiver located in the receiving unit **360** may receive the resonance power from the source resonator through the at least one target resonator. In one or more embodiments, the resonance power receiver may be configured to charge a battery by converting the received resonance power to DC power using the rectifier. It should be appreciated that the receiving unit **360** need not be configured the same as the source resonance unit **310**.

For example, the power converter **370** may convert AC power of a voltage source to DC power. The power converter **370** may include a switching mode power supply (SMPS). The power converter **370** may convert AC power supplied from an outside to DC power. The power converter **370** may then transmit the DC power to the input power unit **340**. The AC power may be 220V in some instances.

In the roof-type charging apparatus using the resonance power transmission, the matching unit **320** may be connected from the predetermined area of the frame of the source resonator to a center area of the source resonator, and the input power unit **340** may be located below the center area of the source resonator **310**.

The roof-type charging apparatus using the resonance power transmission may include the matching unit **320** located in the center of the source resonator, the connecting unit **330** located under the matching unit **320**, and the input power unit **340** located under the connecting unit **330**. For example, the supporting unit **350** may be located in a bottom of the input power unit **340**, and may support the roof-type charging apparatus using the resonance power transmission.

FIG. **4** illustrates a location where a target device is charged in a roof-type charging apparatus using resonance power transmission.

Referring to FIG. **4**, first and second target devices **420** and **430** may be placed at the bottom of a source resonator **410**. The first and second target devices **420** and **430** may receive a resonance power at a constant efficiency, for instance, even when the target devices **420** and **430** may be located in an area **440** under the source resonator **410** that is different an area defined by the source resonator **410**.

For example, a charging radius **440** may be determined based on the resonance power transmission efficiency. In various implementations, a charging radius up to an area where the resonance power transmission efficiency is about 70% may be determined as the charging radius. The resonance power transmission efficiency may rapidly decrease when the resonance power transmission is attempted outside the charging radius. The charging radius of the source resonator **410** may be determined based on a shape of the roof of the source resonator **410** and/or an intensity of the resonance power.

FIG. **5** illustrates resonance power transmission based on a location of a target resonator in a resonance power receiver.

Referring to FIG. **5**, the resonance power receiver may be placed in a bottom of a source resonator **510**. In this example, the resonance power receiver may include target resonators **530** and **550**, a film, and a battery. When a resonance power is transmitted from the source resonator **510** to the resonance receiver, an Eddy current may be induced by a conductor used for the resonance power receiver and the battery. Resonance power transmission efficiency unfortunately may decrease due to the induced Eddy current. As such, functions of devices constituting a resonance power transmitter and the resonance power receiver may be damaged by the induced Eddy current.

The film may shield against a magnetic field generated due to the Eddy current, while the battery is charged with power. The film may have a high permeability and may have a low loss characteristic to minimize difficulty generated due to the Eddy current. However, when a shielding material is located between a source resonator and a target resonator, an induction scheme may not be able to perform wireless power transmission.

The resonance power receiver may also include a terminal in some embodiments. The terminal may be configured by covering a top of the battery with a shielding material, such as the film, and place the target resonators **530** and **550** on the shielding material. Although, the induction scheme may not be able to perform wireless power transmission when shielding material exists between the target resonator **550** and the source resonator **510**.

Resonance power transmission may be effectively performed through magnetic coupling **520** when the target resonator **530** and the source resonator **510** face each other. However, it should be appreciated that even when the target resonator **550** and the source resonator **510** do not face each other, the resonance power transmission scheme may still effectively perform resonance power transmission, through magnetic coupling **540**. For instance, the resonance power may be transmitted in a radial pattern within a charging radius through magnetic coupling.

FIG. **6** illustrates various examples of source resonators. Although, it will be appreciated that other source resonator configurations are also possible.

As shown, the roof of the source resonator may be configured, for example, as a square or rectangle **610**, a circle **620**, a triangle **630**, or a polygon **640** (octagon shown). An effective charging radius may be determined based on the shape of the roof of the source resonator.

FIG. **7** illustrates a roof-type charging apparatuses using resonance power transmission.

Referring to FIG. **7**, the roof-type charging apparatus using resonance power transmission may be configured as a standard lamp. For example, the matching unit **320** may have a predetermined area and may be connected from a frame of the source resonator to the center. For example, the shape of the roof of the source resonator may be configured as a square or rectangle **710**, a circle **720**, a triangle **730**, a polygon **740** (octagon shown), or the like

FIG. **8** illustrates a resonator **800** having a two-dimensional (2D) structure.

Referring to FIG. **8**, the resonator **800** having the 2D structure may include a transmission line, a capacitor **820**, a matcher **830**, and conductors **841** and **842**. The transmission line may include, for instance, a first signal conducting portion **811**, a second signal conducting portion **812**, and a ground conducting portion **813**.

The capacitor **820** may be inserted or otherwise positioned in series between the first signal conducting portion **811** and the second signal conducting portion **812** so that an electric field may be confined within the capacitor **820**. In various implementations, the transmission line may include at least one conductor in an upper portion of the transmission line, and may also include at least one conductor in a lower portion of the transmission line. A current may flow through the at least one conductor disposed in the upper portion of the transmission line and the at least one conductor disposed in the lower portion of the transmission may be electrically grounded. As shown in FIG. **8**, the resonator **800** may be configured to have a generally 2D structure. The transmission line may include the first signal conducting portion **811** and the second signal conducting portion **812** in the upper portion of the transmission line, and may include the ground conducting portion **813** in the lower portion of the transmission line. As shown, the first signal conducting portion **811** and the second signal conducting portion **812** may be disposed to face the ground conducting portion **813** with current flowing through the first signal conducting portion **811** and the second signal conducting portion **812**.

In some implementations, one end of the first signal conducting portion **811** may be electrically connected (i.e., shorted) to a conductor **842**, and another end of the first signal conducting portion **811** may be connected to the capacitor **820**. And one end of the second signal conducting portion **812** may be grounded to the conductor **841**, and another end of the second signal conducting portion **812** may be connected to the capacitor **820**. Accordingly, the first signal conducting portion **811**, the second signal conducting portion **812**, the ground conducting portion **813**, and the conductors **841** and **842** may be connected to each other, such that the resonator **800** may have an electrically "closed-loop structure." The term "closed-loop structure" as used herein, may include a polygonal structure, for example, a circular structure, a rectangular structure, or the like that is electrically closed.

The capacitor **820** may be inserted into an intermediate portion of the transmission line. For example, the capacitor **820** may be inserted into a space between the first signal conducting portion **811** and the second signal conducting portion **812**. The capacitor **820** may be configured, in some instances, as a lumped element, a distributed element, or the like. In one implementation, a distributed capacitor may be configured as a distributed element and include zigzagged conductor lines and a dielectric material having a relatively high permittivity between the zigzagged conductor lines.

When the capacitor **820** is inserted into the transmission line, the resonator **800** may have a property of a metamaterial, as discussed above. For example, the resonator **800** may have a negative magnetic permeability due to the capacitance of the capacitor **820**. If so, the resonator **800** may be referred to as a mu negative (MNG) resonator. Various criteria may be applied to determine the capacitance of the capacitor **820**. For example, the various criteria for enabling the resonator **800** to have the characteristic of metamaterial may include one or more of the following:, a criterion for enabling the resonator **800** to have a negative magnetic permeability in a target frequency, a criterion for enabling the resonator **800** to have a zeroth order resonance characteristic in the target frequency, or the like.

The resonator **800**, also referred to as the MNG resonator **800**, may also have a zeroth order resonance characteristic (i.e., having, as a resonance frequency, a frequency when a propagation constant is "0"). If the resonator **800** has a zeroth order resonance characteristic, the resonance frequency may be independent with respect to a physical size of the MNG resonator **800**. Moreover, by appropriately designing the capacitor **820**, the MNG resonator **800** may sufficiently change the resonance frequency without substantially changing the physical size of the MNG resonator **800** may not be changed.

In a near field, for instance, the electric field may be concentrated on the capacitor **820** inserted into the transmission line. Accordingly, due to the capacitor **820**, the magnetic field may become dominant in the near field. In one or more embodiments, the MNG resonator **800** may have a relatively high Q-factor using the capacitor **820** of the lumped element. Thus, it may be possible to enhance power transmission efficiency. For example, the Q-factor indicates a level of an ohmic loss or a ratio of a reactance with respect to a resistance in the wireless power transmission. The efficiency of the wireless power transmission may increase according to an increase in the Q-factor.

The MNG resonator **800** may include a matcher **830** for impedance-matching. For example, the matcher **830** may be configured to appropriately determine and adjust the strength of a magnetic field of the MNG resonator **800**, for instance. Depending on the configuration, current may flow in the MNG resonator **800** via a connector, or may flow out from the MNG resonator **800** via the connector. The connector may be connected to the ground conducting portion **813** or the matcher **830**. In some instances, power may be transferred through coupling without using a physical connection between the connector and the ground conducting portion **813** or the matcher **830**.

As shown in FIG. **8**, the matcher **830** may be positioned within the loop formed by the loop structure of the resonator **800**. The matcher **830** may adjust the impedance of the resonator **800** by changing the physical shape of the matcher **830**. For example, the matcher **830** may include the conductor **831** for the impedance-matching positioned in a location that is separate from the ground conducting portion **813** by a distance h. Accordingly, the impedance of the resonator **800** may be changed by adjusting the distance h.

In some instances, a controller may be provided to control the matcher **830** which generates and transmits a control signal to the matcher **830** directing the matcher to change its physical shape so that the impedance of the resonator may be adjusted. For example, the distance h between a conductor **831** of the matcher **830** and the ground conducting portion **813** may be increased or decreased based on the control signal. The controller may generate the control signal based on various factors.

As shown in FIG. **8**, the matcher **830** may be configured as a passive element such as, for example, the conductor **831**. Of course, in other embodiments, the matcher **830** may be configured as an active element such as, for example, a diode, a transistor, or the like. If the active element is included in the matcher **830**, the active element may be driven based on the control signal generated by the controller, and the impedance of the resonator **800** may be adjusted based on the control signal. For example, when the active element is a diode is included in the matcher **830**, the impedance of the resonator **800** may be adjusted depending on whether the diode is in an ON state or in an OFF state.

In some instances, a magnetic core may be further provided to pass through the MNG resonator **800**. The magnetic core may perform a function of increasing a power transmission distance.

FIG. **9** illustrates a resonator **900** having a three-dimensional (3D) structure.

Referring to FIG. **9**, the resonator **900** having the 3D structure may include a transmission line and a capacitor **920**. The transmission line may include a first signal conducting portion **911**, a second signal conducting portion **912**, and a ground conducting portion **913**. The capacitor **920** may be inserted, for instance, in series between the first signal conducting portion **911** and the second signal conducting portion **912** of the transmission link, such that an electric field may be confined within the capacitor **920**.

As shown in FIG. **9**, the resonator **900** may have a generally 3D structure. The transmission line may include the first signal conducting portion **911** and the second signal conducting portion **912** in an upper portion of the resonator **900**, and may include the ground conducting portion **913** in a lower portion of the resonator **900**. The first signal conducting portion **911** and the second signal conducting portion **912** may be disposed to face the ground conducting portion **913**. In this arrangement, current may flow in an x direction through the first signal conducting portion **911** and the second signal conducting portion **912**. Due to the current, a magnetic field H(W) may be formed in a −y direction. However, it will be appreciated that the magnetic field H(W) might also be formed in the opposite direction (e.g., the +y direction) in other implementations.

In one or more embodiments, one end of the first signal conducting portion **911** may be electrically connected (i.e., shorted) to a conductor **942**, and another end of the first signal conducting portion **911** may be connected to the capacitor **920**. One end of the second signal conducting portion **912** may be grounded to the conductor **941**, and another end of the second signal conducting portion **912** may be connected to the capacitor **920**. Accordingly, the first signal conducting portion **911**, the second signal conducting portion **912**, the ground conducting portion **913**, and the conductors **941** and **942** may be connected to each other, whereby the resonator **900** may have an electrically "closed-loop structure."

As shown in FIG. **9**, the capacitor **920** may be inserted or otherwise positioned between the first signal conducting portion **911** and the second signal conducting portion **912**. For example, the capacitor **920** may be inserted into a space between the first signal conducting portion **911** and the second signal conducting portion **912**. The capacitor **920** may include, for example, a lumped element, a distributed element, or the like. In one implementation, a distributed capacitor having the shape of the distributed element may include zigzagged conductor lines and a dielectric material having a relatively high permittivity positioned between the zigzagged conductor lines.

When the capacitor **920** is inserted into the transmission line, the resonator **900** may have a property of a metamaterial, in some instances, as discussed above.

For example, when a capacitance of the capacitor inserted is a lumped element, the resonator **900** may have the characteristic of the metamaterial. When the resonator **900** has a negative magnetic permeability by appropriately adjusting the capacitance of the capacitor **920**, the resonator **900** may also be referred to as an MNG resonator. Various criteria may be applied to determine the capacitance of the capacitor **920**. For example, the various criteria may include, for instance, one or more of the following: a criterion for enabling the resonator **900** to have the characteristic of the metamaterial, a criterion for enabling the resonator **900** to have a negative magnetic permeability in a target frequency, a criterion enabling the resonator **900** to have a zeroth order resonance characteristic in the target frequency, or the like. Based on at least one criterion among the aforementioned criteria, the capacitance of the capacitor **920** may be determined.

The resonator **900**, also referred to as the MNG resonator **900**, may have a zeroth order resonance characteristic (i.e., having, as a resonance frequency, a frequency when a propagation constant is "0"). If the resonator **900** has the zeroth order resonance characteristic, the resonance frequency may be independent with respect to a physical size of the MNG resonator **900**. Thus, by appropriately designing the capacitor **920**, the MNG resonator **900** may sufficiently change the resonance frequency without substantially changing the physical size of the MNG resonator **900**.

Referring to the MNG resonator **900** of FIG. **9**, in a near field, the electric field may be concentrated on the capacitor **920** inserted into the transmission line. Accordingly, due to the capacitor **920**, the magnetic field may become dominant in the near field. And, since the MNG resonator **900** having the zeroth-order resonance characteristic may have characteristics similar to a magnetic dipole, the magnetic field may become dominant in the near field. A relatively small amount of the electric field formed due to the insertion of the capacitor **920** may be concentrated on the capacitor **920** and thus, the magnetic field may become further dominant.

Also, the MNG resonator **900** may include a matcher **930** for impedance-matching. The matcher **930** may be configured to appropriately adjust the strength of magnetic field of the MNG resonator **900**. The impedance of the MNG resonator **900** may be determined by the matcher **930**. In one or more implementations, a current may flow in the MNG resonator **900** via a connector **940**, or may flow out from the MNG resonator **900** via the connector **940**. And the connector **940** may be connected to the ground conducting portion **913** or the matcher **930**.

As shown in FIG. **9**, the matcher **930** may be positioned within the loop formed by the loop structure of the resonator **900**. The matcher **930** may be configured to adjust the impedance of the resonator **900** by changing the physical shape of the matcher **930**. For example, the matcher **930** may include the conductor **931** for the impedance-matching in a location separate from the ground conducting portion **913** by a distance h. The impedance of the resonator **900** may be changed by adjusting the distance h.

In some implementations, a controller may be provided to control the matcher **930**. In this case, the matcher **930** may change the physical shape of the matcher **930** based on a control signal generated by the controller. For example, the distance h between the conductor **931** of the matcher **930** and the ground conducting portion **913** may be increased or decreased based on the control signal. Accordingly, the physical shape of the matcher **930** may be changed such that the impedance of the resonator **900** may be adjusted. The distance h between the conductor **931** of the matcher **930** and the ground conducting portion **913** may be adjusted using a variety of schemes. For example, a plurality of conductors may be included in the matcher **930** and the distance h may be adjusted by adaptively activating one of the conductors. Alternatively or additionally, the distance h may be adjusted by adjusting the physical location of the conductor **931** up and down. For instance, the distance h may be controlled based on the control signal of the controller. The controller may generate the control signal using various factors. As shown in FIG. **9**, the matcher **930** may be configured as a passive element such as, for instance, the conductor **931**. Of course, in other embodiments, the matcher **930** may be configured as an active element such as, for example, a diode, a transistor, or the like. When the active element is included in the matcher **930**, the active element may be driven based on the control signal generated by the controller, and the impedance of the resonator **900** may be adjusted based on the control signal. For example, if the active element is a diode included in the matcher **930**, the impedance of the resonator **900** may be adjusted depending on whether the diode is in an ON state or in an OFF state.

In some implementations, a magnetic core may be further provided to pass through the resonator **900** configured as the MNG resonator. The magnetic core may perform a function of increasing a power transmission distance.

FIG. **10** illustrates a resonator **1000** for a wireless power transmission configured as a bulky type.

As used herein, the term "bulky type" may refer to a seamless connection connecting at least two parts in an integrated form.

Referring to FIG. **10**, a first signal conducting portion **1011** and a second signal conducting portion **1012** may be integrally formed instead of being separately manufactured and thereby be connected to each other. Similarly, the second signal conducting portion **1012** and a conductor **1041** may also be integrally manufactured.

When the second signal conducting portion **1012** and the conductor **1041** are separately manufactured and then are connected to each other, a loss of conduction may occur due to a seam **1050**. Thus, in some implementations, the second signal conducting portion **1012** and the conductor **1041** may be connected to each other without using a separate seam (i.e., seamlessly connected to each other). Accordingly, it is possible to decrease a conductor loss caused by the seam **1050**. For instance, the second signal conducting portion **1012** and a ground conducting portion **1013** may be seamlessly and integrally manufactured. Similarly, the first signal conducting portion **1011**, the conductor **1142** and the ground conducting portion **1013** may be seamlessly and integrally manufactured. A matcher **1030** may be provided that is similarly constructed as described herein in one or more embodiments.

FIG. **11** illustrates a resonator **1100** for a wireless power transmission, configured as a hollow type.

Referring to FIG. **11**, each of a first signal conducting portion **1111**, a second signal conducting portion **1112**, a ground conducting portion **1113**, and conductors **1141** and **1142** of the resonator **1100** configured as the hollow type structure. As used herein, the term "hollow type" refers to a configuration that may include an empty space inside.

For a given resonance frequency, an active current may be modeled to flow in only a portion of the first signal conducting portion **1111** instead of all of the first signal conducting portion **1111**, the second signal conducting portion **1112** instead of all of the second signal conducting portion **1112**, the ground conducting portion **1113** instead of all of the ground conducting portion **1113**, and the conductors **1141** and **1142** instead of all of the conductors **1141** and **1142**. When a depth of each of the first signal conducting portion **1111**, the second signal conducting portion **1112**, the ground conducting portion **1113**, and the conductors **1141** and **1142** is significantly deeper than a corresponding skin depth in the given resonance frequency, it may be ineffective. The significantly deeper depth may, however, increase a weight or manufacturing costs of the resonator **1100** in some instances.

Accordingly, for the given resonance frequency, the depth of each of the first signal conducting portion **1111**, the second signal conducting portion **1112**, the ground conducting portion **1113**, and the conductors **1141** and **1142** may be appropriately determined based on the corresponding skin depth of each of the first signal conducting portion **1111**, the second signal conducting portion **1112**, the ground conducting portion **1113**, and the conductors **1141** and **1142**. When each of the first signal conducting portion **1111**, the second signal conducting portion **1112**, the ground conducting portion **1113**, and the conductors **1141** and **1142** has an appropriate depth deeper than a corresponding skin depth, the resonator **1100** may become light, and manufacturing costs of the resonator **1100** may also decrease.

For example, as shown in FIG. **11**, the depth of the second signal conducting portion **1112** (as further illustrated in the enlarged view region **1160** indicated by a circle) may be determined as "d" mm and d may be determined according to

$$d = \frac{1}{\sqrt{\pi f \mu \sigma}}.$$

Here, f denotes a frequency, μ denotes a magnetic permeability, and σ denotes a conductor constant. In one implementation, when the first signal conducting portion **1111**, the second signal conducting portion **1112**, the ground conducting portion **1113**, and the conductors **1141** and **1142** are made of a copper and they may have a conductivity of 5.8×10^7 siemens per meter ($S\cdot m^{-1}$), the skin depth may be about 0.6 mm with respect to 10 kHz of the resonance frequency and the skin depth may be about 0.006 mm with respect to 100 MHz of the resonance frequency.

A capacitor **1120** and a matcher **1130** may be provided that are similarly constructed as described herein in one or more embodiments.

FIG. **12** illustrates a resonator **1200** for a wireless power transmission using a parallel-sheet.

Referring to FIG. **12**, the parallel-sheet may be applicable to each of a first signal conducting portion **1211** and a second signal conducting portion **1212** included in the resonator **1200**.

Each of the first signal conducting portion **1211** and the second signal conducting portion **1212** may not be a perfect conductor and thus, may have an inherent resistance. Due to this resistance, an ohmic loss may occur. The ohmic loss may decrease a Q-factor and also decrease a coupling effect.

By applying the parallel-sheet to each of the first signal conducting portion **1211** and the second signal conducting portion **1212**, it may be possible to decrease the ohmic loss, and to increase the Q-factor and the coupling effect. Referring to the enlarges view portion **1270** indicated by a circle, when the parallel-sheet is applied, each of the first signal conducting portion **1211** and the second signal conducting portion **1212** may include a plurality of conductor lines. The plurality of conductor lines may be disposed in parallel, and may be electrically connected (i.e., shorted) at an end portion of each of the first signal conducting portion **1211** and the second signal conducting portion **1212**.

When the parallel-sheet is applied to each of the first signal conducting portion **1211** and the second signal conducting portion **1212**, the plurality of conductor lines may be disposed in parallel. Accordingly, a sum of resistances having the conductor lines may decrease. Consequently, the resistance loss may decrease, and the Q-factor and the coupling effect may increase.

A capacitor **1220** and a matcher **1230** positioned on the ground conducting portion **1213** may be provided that are similarly constructed as described herein in one or more embodiments.

FIG. **13** illustrates a resonator **1300** for a wireless power transmission, including a distributed capacitor.

Referring to FIG. **13**, a capacitor **1320** included in the resonator **1300** is configured for the wireless power transmission. A capacitor used as a lumped element may have a relatively high equivalent series resistance (ESR). A variety of schemes have been proposed to decrease the ESR contained in the capacitor of the lumped element. According to an embodiment, by using the capacitor **1320** as a distributed element, it may be possible to decrease the ESR. As will be appreciated, a loss caused by the ESR may decrease a Q-factor and a coupling effect.

As shown in FIG. **13**, the capacitor **1320** may be configured as a conductive line having a zigzagged structure.

By employing the capacitor **1320** as the distributed element, it may be possible to decrease the loss occurring due to the ESR in some instances. In addition, by disposing a plurality of capacitors as lumped elements, it is possible to decrease the loss occurring due to the ESR. Since a resistance of each of the capacitors as the lumped elements decreases through a parallel connection, active resistances of parallel-connected capacitors as the lumped elements may also decrease whereby the loss occurring due to the ESR may decrease. For example, by employing ten capacitors of 1 pF each instead of using a single capacitor of 10 pF, it may be possible to decrease the loss occurring due to the ESR in some instances.

FIG. **14**A illustrates the matcher **830** used in the resonator **800** provided in the 2D structure of FIG. **8**, and FIG. **14**B illustrates an example of the matcher **930** used in the resonator **900** provided in the 3D structure of FIG. **9**.

FIG. **14**A illustrates a portion of the 2D resonator including the matcher **830**, and FIG. **14**B illustrates a portion of the 3D resonator of FIG. **9** including the matcher **930**.

Referring to FIG. **14**A, the matcher **830** may include the conductor **831**, a conductor **832**, and a conductor **833**. The conductors **832** and **833** may be connected to the ground conducting portion **813** and the conductor **831**. The impedance of the 2D resonator may be determined based on a distance h between the conductor **831** and the ground conducting portion **813**. The distance h between the conductor **831** and the ground conducting portion **813** may be controlled by the controller. The distance h between the conductor **831** and the ground conducting portion **813** can be adjusted using a variety of schemes. For example, the variety of schemes may include, for instance, one or more of the following: a scheme of adjusting the distance h by adaptively activating one of the conductors **831**, **832**, and **833**, a scheme of adjusting the physical location of the conductor **831** up and down, or the like.

Referring to FIG. **14**B, the matcher **930** may include the conductor **931**, a conductor **932**, a conductor **933** and conductors **941** and **942**. The conductors **932** and **933** may be connected to the ground conducting portion **913** and the conductor **931**. Also, the conductors **941** and **942** may be connected to the ground conducting portion **913**. The impedance of the 3D resonator may be determined based on a distance h between the conductor **931** and the ground conducting portion **913**. The distance h between the conductor **931** and the ground conducting portion **913** may be controlled by the controller, for example. Similar to the matcher **830** included in the 2D structured resonator, in the matcher **930** included in the 3D structured resonator, the distance h between the conductor **931** and the ground conducting portion **913** may be adjusted using a variety of schemes. For example, the variety of schemes may include, for instance, one or more of the following: a scheme of adjusting the distance h by adaptively activating one of the conductors **931**, **932**, and **933**, a scheme of adjusting the physical location of the conductor **931** up and down, or the like.

In some implementations, the matcher may include an active element. Thus, a scheme of adjusting an impedance of a resonator using the active element may be similar as described above. For example, the impedance of the resonator may be adjusted by changing a path of a current flowing through the matcher using the active element.

FIG. **15** illustrates one example of an equivalent circuit of the resonator **800** for the wireless power transmission of FIG. **8**.

The resonator **800** of FIG. **8** for the wireless power transmission may be modeled to the equivalent circuit of FIG. **15**. In the equivalent circuit depicted in FIG. **15**, L_R denotes an inductance of the power transmission line, C_L denotes the capacitor **820** that is inserted in a form of a lumped element in the middle of the power transmission line, and C_R denotes a capacitance between the power transmissions and/or ground of FIG. **8**.

In some instances, the resonator **800** may have a zeroth resonance characteristic. For example, when a propagation constant is "0", the resonator **800** may be assumed to have ω_{MZR} as a resonance frequency. The resonance frequency ω_{MZR} may be expressed by Equation 2.

$$\omega_{MZR} = \frac{1}{\sqrt{L_R C_L}} \quad \text{[Equation 2]}$$

In Equation 2, MZR denotes a Mu zero resonator.

Referring to Equation 2, the resonance frequency ω_{MZR} of the resonator **800** may be determined by L_R/C_L. A physical size of the resonator **800** and the resonance frequency ω_{MZR} may be independent with respect to each other. Since the physical sizes are independent with respect to each other, the physical size of the resonator **800** may be sufficiently reduced.

Example embodiments may provide a roof-type charging apparatus using resonance power transmission, and the roof-type charging apparatus may enable a source resonator and a target device to be separated by a predetermined distance away from each other and thus, may stabilize a coupling impedance of two resonators to be a predetermined impedance.

Example embodiments may provide a roof-type charging apparatus using resonance power transmission, and the roof-type charging apparatus may stabilize a coupling impedance to be a predetermined impedance and thus, a power amplifier and a rectifier may be easily matched.

Example embodiments may provide a roof-type charging apparatus using resonance power transmission, and the roof-type charging apparatus may stabilize a coupling impedance to be a predetermined impedance and thus, a change in the impedance may be low and multiple target devices may be charged.

Example embodiments may adjust a size of a source resonator and thus, a charging radius where a target device is charged may be controlled and multiple target devices may be charged.

In various embodiments, one or more of the processes, functions, methods described above may be recorded, stored, or fixed in one or more computer-readable storage media that includes program instructions to be implemented by a computer to cause a processor to execute or perform the program instructions. The media may also include, alone or in combination with the program instructions, data files, data structures, and the like. The media and program instructions may be those specially designed and constructed, or they may be of the kind well-known and available to those having skill in the computer software arts. Examples of computer-readable media include magnetic media, such as hard disks, floppy disks, and magnetic tape; optical media such as CD ROM disks and DVDs; magneto-optical media, such as optical disks; and hardware devices that are specially configured to store and perform program instructions, such as read-only memory (ROM), random access memory (RAM), flash memory, and the like. Examples of program instructions include machine code, such as produced by a compiler, and files containing higher level code that may be executed by the computer using an interpreter. The described hardware devices may be configured to act as one or more software modules in order to perform the operations and methods described above, or vice versa. In addition, a computer-readable storage medium may be distributed among computer systems connected through a network and computer-readable codes or program instructions may be stored and executed in a decentralized manner.

It is understood that the terminology used herein, may be different in other applications or when described by another person of ordinary skill in the art.

A number of example embodiments have been described above. Nevertheless, it should be understood that various modifications may be made. For example, suitable results may be achieved if the described techniques are performed in a different order and/or if components in a described system, architecture, device, or circuit are combined in a different manner and/or replaced or supplemented by other components or their equivalents. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A roof-type charging apparatus using resonance power transmission, the apparatus comprising:

a source resonance unit included in a roof of the charging apparatus, the source resonance unit configured to transmit resonance power via a source resonator having a generally planar loop configuration and defining a space therein;

a receiving unit on which a target resonator is to be positioned to receive the resonance power transmitted from the source resonator;

a connecting unit configured to separate the source resonator and the receiving unit by a predetermined distance; and

a matching unit configured to match a coupling impedance of the source resonator and the target resonator that receives the resonance power transmission,

wherein the matching unit further controls the connecting unit to control a vertical distance between the roof of the apparatus and the receiving unit for coupling impedance matching between the source resonator and the target resonator.

2. The apparatus of claim **1**, wherein the source resonator and the receiving unit are positioned generally parallel with respect to one another.

3. The apparatus of claim **1**, wherein the source resonator is one of:

square-shaped, rectangular-shaped, circle-shaped, oval-shaped, elliptical-shaped, triangle-shaped, octagon-shaped and polygon-shaped.

4. The apparatus of claim **1**, wherein the source resonator defines an effective charging radius of the source resonator as a minimal distance at which power transfer occurs.

5. The apparatus of claim **4**, wherein a target resonator that receives the resonance power transmission is positioned inside the effective charging radius of the source resonator.

6. The apparatus of claim **1**, further comprising:

an input power unit configured to generate a resonance power based on a resonance frequency, and to provide the resonance power to the source resonator.

7. The apparatus of claim **6**, wherein the input power unit is located below the space defined by the source resonator.

8. The apparatus of claim **1**, wherein, during resonance power transmission, the connecting unit controls the vertical distance between the roof of the apparatus and the receiving unit such that the source resonator is at least a ten centimeters (cm) above the target resonator during resonation.

9. The apparatus of claim **1**, wherein the matching unit is positioned in the space defined by the source resonator.

10. The apparatus of claim **1**, wherein the source resonance unit includes a frame configured to connect the source resonator to the connecting unit.

11. The apparatus of claim **1**, further comprising:

a power converter configured to convert alternating current (AC) power of a voltage source to a direct current (DC) power.

12. The apparatus of claim **1**, wherein the connecting unit comprises a hollow cylinder, and a cable passing through the inside of the hollow cylinder.

13. The apparatus of claim **12**, wherein the hollow cylinder is formed of an insulative material.

14. The apparatus of claim **1**, wherein the predetermined distance is adjustable thereby providing impedance matching between the source resonator and a target resonator that receives the resonance power transmission.

15. The apparatus of claim **1**, wherein the source resonance unit includes an extension controller configured to adjust an effective charging radius of the source resonator defined as a minimal distance at which power transfer occurs.

16. The apparatus of claim **1**, further comprising:

a supporting unit configured to support the apparatus.

17. A method of transmitting resonance power, the method comprising:

transmitting resonance power using a source resonator having a generally planar loop configuration defining a space therein, the source resonator being included in a roof of a wireless power transmission apparatus;

receiving by a target resonator positioned on a receiving unit the resonance power transmitted from the source resonator; and

adjusting a vertical distance between the roof of the apparatus and the receiving unit for coupling impedance matching between the source resonator and the target resonator.

18. The method of claim **17**, wherein the source resonator is one of: square-shaped, rectangular-shaped, circle-shaped, triangle-shaped, octagon-shaped and polygon-shaped.

19. The method of claim **17**, wherein the source resonator defines an effective charging radius of the source resonator as a minimal distance at which power transfer occurs.

20. The method of claim **17**, wherein a target resonator that receives the resonance power transmission is positioned inside an effective charging radius of the source resonator defined as a minimal distance at which power transfer occurs.

21. The method of claim **17**, further comprising:

adjusting an effective charging radius of the source resonator.

22. A roof-type charging apparatus using resonance power transmission, the apparatus comprising:

a source resonance unit included in a roof of the charging apparatus, the source resonance unit configured to transmit resonance power via a source resonator having a generally planar loop configuration and defining a space therein;

a receiving unit on which a target resonator is to be positioned to receive the resonance power transmitted from the source resonator;

a matching unit located in a predetermined area of a frame of the source resonator and configured to match, to a predetermined value, a coupling impedance between the source resonator and the target resonator that receives the resonance power transmission;

an input power unit configured to generate resonance power based on a resonance frequency, and to provide the resonance power to the source resonator;

a connecting unit configured to separate the source resonator and the receiving unit by a predetermined distance; and

a supporting unit connected to the input power unit and configured to support the roof-type charging apparatus,

wherein the matching unit further controls the connecting unit to control a vertical distance between the roof of the apparatus and the receiving unit for coupling impedance matching between the source resonator and the target resonator.

* * * * *